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SIMULATION OF A FIELD ARTILLERY BATTERY IN SUPPORT OF THE DEFEN--ETC(U)

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SIMULATION OF A FIELD ARTILLERY BATTERY
IN SUPPORT OF THE DEFENSE

by

Lee Samuel Dewald Sr.

June 1977

Thesis Advisor: S. H. Parry

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Simulation of a Field Artillery Battery in Support of the Defense

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ABSTRACT

This thesis presents a queuing simulation model of a field artillery battery (155mm) in direct support of defensive operations. The model simulates the four major components of the battery: the forward observer in his roles in target acquisition, transmission of calls for fire, and in the adjustment of fire missions; the communications system; the fire direction center; and the firing battery. The model was exercised under a series of different battle scenarios in order to analyze the system response time and capability to engage targets. To this end statistics are generated for each of the four major components. Suggestions are included for application of this model to analyze major alterations in the system e.g., improved communications, faster target acquisition or fire direction computation. Capabilities to model other larger units, different missions, and terrain are also discussed.

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I. INTRODUCTION

A. BACKGROUND AND PURPOSE

The Field Artillery has been in existence as a combat arm for centuries undergoing a remarkable transformation from the simplest of early catapults hurling boulders against stone walls at relatively close range to the most intricate of power-assisted cannons capable of delivering nuclear projectiles on targets miles away. Although the system capabilities, deployment doctrine and unit configurations are in constant evolution, the mission of the Field Artillery to provide timely and accurate firepower to meet the requirements of the supported units has never changed.

The purpose of the myriad of fire support studies to date has been in part to determine the optimal mix of artillery systems necessary to accomplish the mission in the broadest possible interpretation. The studies are conducted for divisions and higher units engaged in two or three day wars where the enemy targets were developed from independent war games and/or map studies for specific scenarios. The planners were constantly at odds with the champions of tractability and simplicity of design on one hand and the proponents of detail on the other. They were continually confronted also with the reality that each design of increased detail required additional computer time.

Studies of the type described above are appropriate for the analyses required by policy-makers and strategists at the highest levels. Such individuals are also the ones with the funds necessary to support such projects. But today even commanders at the division and corps level are utilizing the "back of the envelope" analyses to develop an understanding of the problems arising in such areas as personnel utilization, repair parts management, and artillery basic loads.

It is the purpose of this thesis to present a basic model capable of being adapted to different levels of increased sophistication, which represents the artillery fire support system in terms of target servicing times and identifies the bottlenecks in the system.

B. THE FIELD ARTILLERY GUNNERY TEAM

Before describing the artillery target servicing model, the fundamentals of the artillery fire support system are described as an aid to those readers not thoroughly acquainted with the system.

The field artillery gunnery team is composed of the forward observer (FO), the fire direction center (FDC), and the firing battery (FB). All elements of the team are interconnected by various communications systems. The FO detects and reports to the FDC the location of suitable targets, initiates calls for fire starting with the highest priority target, and conducts adjustments on the previously

fired rounds if necessary. In the FDC the information received from the FO is evaluated, firing data is determined, and the data is furnished to the FB in the form of fire commands. In the FB the data are applied to the weapons and fired. The communications system currently consists of radio and telephone links. Usually the FDC and the FO communicate by radio. The FDC and FB use field telephones installed within the battery area. The FO's and the FDC of each battery are the stations in the battery fire direction (FD) net and each FD net is assigned one frequency. Obvious results of this arrangement are as follows:

1. only one person talks at a time;
2. anyone else in the net knows what is being transmitted to and by whom;
3. each element is capable of initiating a message at any time after the net is in operation.

The specific tasks associated with each type of combat situation which are to be performed by each element of the gunnery team have been outlined by the Department of the Army in a series of Army Training and Evaluation Programs (ARTEP). A performance standard of time and/or accuracy is assigned to each task enabling a unit to measure its level of training in all areas relating to the capability of successful mission completion. ARTEP No. 6-635 [Ref. 2] was the primary source consulted for determining FO, FDC, and FB service times in the model.

The composition of a field artillery battery is not the same. The number of forward observers and howitzers differ if the unit is composed of 155mm howitzers in direct support versus 175mm howitzers in general support. The 155mm self-propelled (SP) howitzer battery includes three forward observers, a fire direction center, and a firing battery consisting of six 155mm SP howitzers. Table I describes several characteristics and capabilities of the artillery weapon used in this model.

Three batteries as described above comprise the majority of each field artillery (FA) battalion in an armored or mechanized infantry division artillery. Each battalion is in direct support (DS) of one maneuver brigade of the division. A field artillery unit with a DS mission answers calls for fire from the units within the supported brigade; it fires only into the zone of action of that brigade; it provides FO's to each company-sized combat element of the brigade; and each battery is positioned to provide fire support in at least one area of operation of each battalion in the supported brigade.

TABLE I: SELECTED CHARACTERISTICS AND CAPABILITIES OF 155mm HOWITZER M109, SP

Average Muzzle Velocity (meters per second)	540
Maximum range (meters)	14,600
Life in service (rounds)	5,000
Maximum rate of fire (rounds per minute first three minutes)	4
Sustained rate of fire (rounds per minute)	1

In the defense the batteries are positioned as close as practical to the forward edge of the battle area (FEBA), the imaginery line formed by unit positions across the area of operations. This practice enables the defender to engage targets at greater distances from the FEBA and to steadily increase the intensity of the engagement as the targets advance within the range of more weapons. Therefore the artillery gives depth to the battlefield.

The effect of artillery fire is highly dependent upon the nature and location of the target. The artillery is more successful against stationery targets than moving targets and is more effective against targets in the open than those under cover. The artillery is able to inflict considerable damage on troops and trucks and lesser damage on armored vehicles (tanks and armored personnel carriers (APC)). Artillery fire in general does not destroy tanks or APC's but it does have the capability to disrupt an armored attack by obstructing driver vision, impeding communications and suppressing enemy fire.

Detailed information concerning specific functions of any gunnery team element or a particular type of fire mission can be found in FM 6-40 <u>Field Artillery Cannon Gunnery</u> [Ref. 3].

C. MODEL APPROACH

The objective of the analysis presented in this paper is to represent an artillery service process in terms of

component (i.e., forward observer (FO), fire direction center (FDC), guns (FB)) utilization, service times, and the ratio of successfully completed missions to total targets generated. If one views the enemy units or targets as customers and the artillery unit (from the FO to the FB) as the server, then the model most relevant would be one from the birth-death class of models where births come from the target stream reported by the FO and deaths result from completion of effective fire by the FB, or from passage of the duration criterion for the target.

A queuing system is completely defined by the following factors:

1. Input

The information concerning the arrivals is either deterministic or stochastic. Arrivals are homogeneous (i.e., require identical service) or not. They come from a population that is finite or infinite. The rate of arrival is constant or variable. Arrivals may renege or not.

2. Number and Stages of Servers

Service is completed on an arrival by one or one of many identical or different servers, or service is completed after the arrival has visited several stations. The servers may also be permitted to renege on a customer.

3. Waiting-line Discipline

The arrivals at a busy station form queues from which they are selected on first-in first-out (FIFO), last-in first-out (LIFO), priority, or random basis.

4. Output

The information concerning the departures from the system is also deterministic or stochastic.

The literature on queuing models is extensive and the possibility had been investigated by Bonder [Ref. 11] of finding or developing appropriate analytical models which would adequately describe the artillery service process. Of the models reviewed and considered capable of straightforward application, each required a significant number of assumptions. A recapitulation of that survey can be found in Ref. 11. In light of these results, simulation was chosen as the appropriate modeling technique for the analysis of the queuing process as described in the field artillery battery model in Section II.

One advantage of a simulation model is that it provides the opportunity to investigate the performance and interaction of the individual components under simulated real time conditions allowing the overall system capabilities to be analyzed. In Section IIIB the gunnery team is investigated component by component under eight "surge" situations. (A surge situation exists when an artillery unit is unable to engage all known targets within a specified interval.) The results of the simulation runs are evaluated in Section IIIC through the use of a factorial experiment.

The application of simulation models is only restricted by computer assets and the analyst's familiarity with those

available. In Section IV several areas in which the scope of the model could be extended to apply to different situations are proposed.

The computer language chosen for this simulation is IBM General Purpose Simulation System (GPSSV). A brief explanation of GPSS has been included in Appendix A. The GPSS program to include the transaction parameters, functions and variables, and flow chart can be found in Appendices B, C, and D. The program output and resultant statistics have been tabulated and placed in Appendix E.

II. DESCRIPTION OF SIMULATION MODEL

A. THE FIELD ARTILLERY BATTERY MODEL

The model as depicted in Fig. 1 is characteristic of all batteries in a direct support role. Only the firing battery service time (time to lay, load, and shoot the weapons) and the time of flight are different from one battery type to the next. The inputs are enemy platoon-sized elements which form a finite target population in each FO zone.

The service configuration consists of four stages of intermediate processing (FO, FD Net, FDC, FB). The FO stage consists of three independent parallel single-server stations. At one of these stations the information gathered by the FO about a target is formulated into a request for fire. The FD Net is a single-server station through which the request for fire is transmitted to the FDC. The FDC stage consists of one multiple-server station capable of simultaneously calculating data for multiple fire missions from the requests for fire received from several FO's. The FB stage is a single-server which fires the missions.

Queues can develop at the FO, the FD Net, and the FB. Each FO queue discipline is priority and the priority schemes are based on the military worth of the target. The FD Net queue discipline is usually random selection. The queue at the FB is a FIFO queue the length of which is

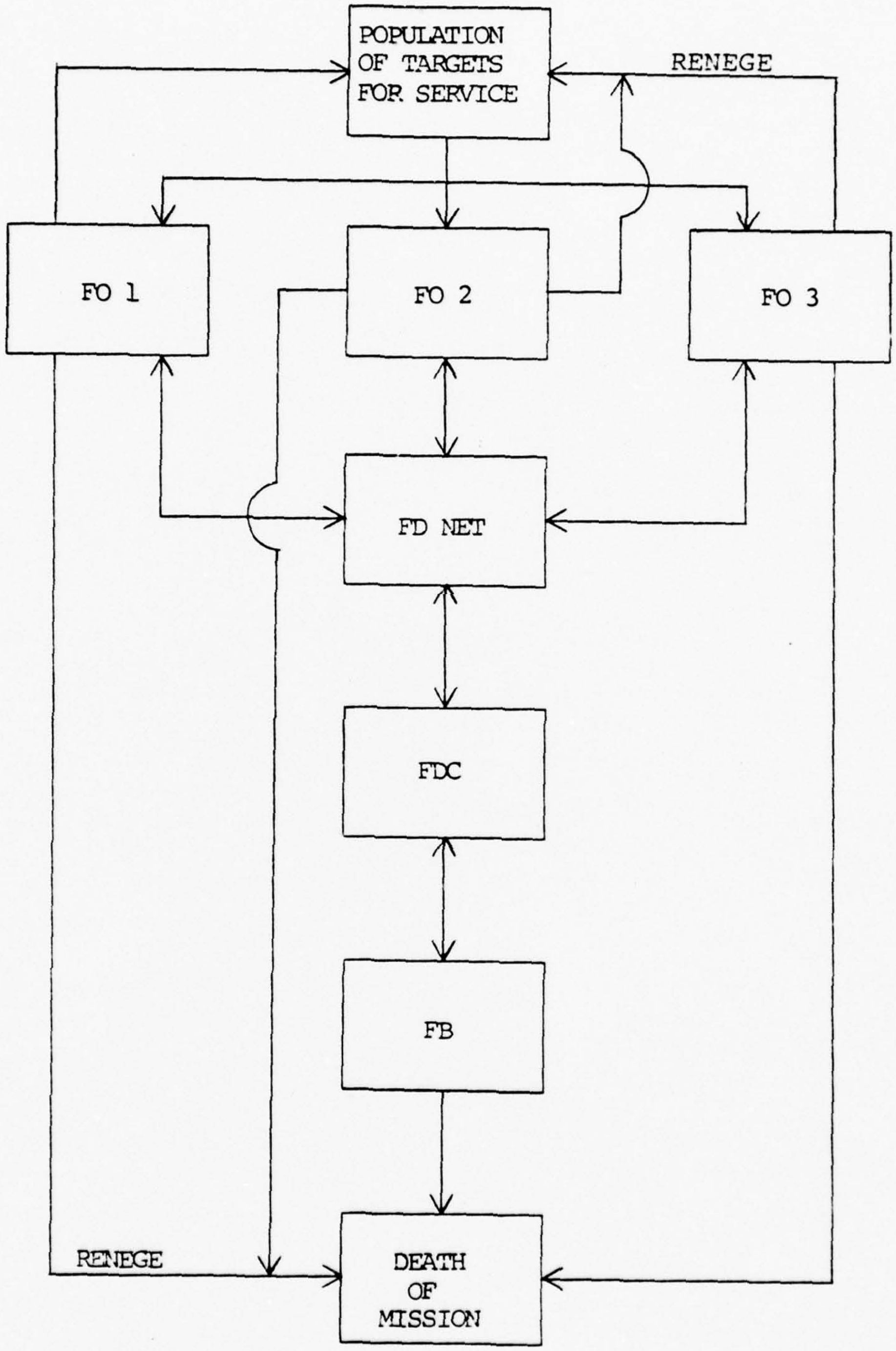

Figure 1. Field Artillery Battery Fire Support System

bounded above by the number of missions that the FDC is capable of processing at any time. When a queue is permitted to form at the FDC, the discipline is a complicated priority scheme which integrates asset availability of the system with the military worth of the target.

If the total time to engage a target exceeds a given threshold, the FO may be unable to continue the service by adjusting the rounds if the target is no longer intervisible. In this sense the targets renege. The targets may reappear at some future time and closer range. The gunnery team reneges on the targets whenever the targets close to within a specified range of the FEBA.

The system output of interest is the distribution of departures (i.e. those targets which received the completed service). The main effects and interaction effects of target range at detection, speed and interarrival time on the number of targets successfully engaged in the simulation runs are analyzed based on multiple executions of the model.

B. MODELING ASSUMPTIONS

The field artillery battery simulated in this model was a 155mm SP battery and was assumed to be combat ready. It was therefore capable of attaining level one standards as described in Ref. 2.

Although the maximum time for each task is listed in the ARTEP, the distribution of those times is unknown. For the purpose of this simulation a uniform distribution over

a short interval which included the maximum time as the upperbound on the interval was utilized for each service time required in the simulation.

The FO in the defense becomes thoroughly familiar with the terrain in the area of operation. He develops terrain visibility diagrams which enable him to extrapolate an engagement location of a moving target from its direction and speed as it moves from one intervisibility band to the next. He locates on his map prominent terrain features (hilltops, road junctions, church steeples, etc.) and identifies to the FDC those locations which lie on or near likely enemy avenues of approach. The FDC assigns to the FO target numbers for each known location. Therefore it is assumed in the model that the FO is aware of the arrival of a new target when it first becomes intervisible. If the FO is available (i.e. is not involved in one of his other tasks) and a target becomes intervisible, he uses the known-point or shift-from-a-known-point method of target location and engages the targets with fire for effect missions as opposed to adjusting fire first.

A call for fire is evaluated in the FDC. The evaluation process results in the following three decisions:

1. to fire the mission or to pass the information on as intelligence;

2. if the mission is to be fired, is the target appropriate for the available howitzer assets or should the mission be fired simultaneously by several batteries;

3. if the mission is to be fired by the one battery, the appropriate number of rounds, types of fuses and projectiles must be determined.

Since the scenarios portrayed in the model are defensive battles, only requests for fire from the FO's are generated and all are assumed to satisfy the criteria as described above for a fire mission. Additionally the appropriate fuse and projectile combinations are always available. All FDC efforts are directed at computing data for the missions. Other FDC activities, including battery registration and processing of meteorological (MET) messages (calculations to update firing tables to correct for changing meteorological conditions which can have considerable effect on accuracy when firing without adjustment in fire-for-effect missions) are not simulated but assumed to have been accomplished prior to the battles.

It is assumed in the model that all units within the battalion of the simulated battery and those additional batteries usually in general support are overloaded during the simulations so that decision 2 above is assumed to favor engagement by one battery. The implication is that all requests for fire unable to be processed by the simulated battery are returned to the FO. The FO naturally continues to pursue his top priority target as soon as the overload in the FDC is alleviated.

The enemy force is assumed to adhere to the tactics as described in RB 30-1 The Enemy Force [Ref. 9]. Therefore the simulated portion of the enemy force consists of 51 platoons of tank, APC mounted infantry, and anti-tank weapons from a motorized rifle regiment attacking across the three FO zones in the first wave. All units continue the attack direction and speed at all costs, deploy only when forced to do so, and bypass pockets of resistance. Since all forward observers operate on the same frequency it is assumed that they do not call for fire on the same targets.

III. RESULTS OF SIMULATION RUNS

A. GENERAL APPROACH

In order to evaluate the model as a functional representation of a field artillery battery in support of the defense, a series of simulation runs employing different scenarios were made. The attributes that define a particular scenario include:

1. target interarrival time — the time between the arrival of successive enemy units into the combat zone;

2. average detection range — the distance at which the FO identifies a target;

3. target speed — the rate of movement of the individual enemy units through the combat zone;

4. intervisibility segments — those locations on the ground where target and observer are intervisible.

The eight scenarios investigated in this thesis are defined in Table II. The values used for target speed and average detection range correspond to the extremes which are likely to be encountered in a defensive situation. The values of target interarrival times characterize the general defense scenario as a surge scenario. The intervisibility/nonintervisibility segment links are held constant in the eight scenarios in order to define a common terrain type in which the targets will only be intervisible (detectable) 50% of the time.

TABLE II: SCENARIO ATTRIBUTES

SCENARIO	DETECTION RANGE (meters)	TARGET INTERARRIVAL RATE (seconds)	TARGET SPEED (meters/hr)	INTERVISIBILITY/ NONINTERVISIBILITY (meters)
1	3000	5	10,000	200/200
2	3000	5	20,000	200/200
3	5500	5	10,000	200/200
4	5500	5	20,000	200/200
5	3000	12.5	10,000	200/200
6	3000	12.5	20,000	200/200
7	5500	12.5	10,000	200/200
8	5500	12.5	20,000	200/200

Note: The effect produced by the intervisibility/noninter-visibility segment distribution is that a target is intervisible only 50% of the time.

The attributes that describe the gunnery team were incorporated into the model as functions, variables, and operational block entities (see Appendix D).

Since GPSS is a process interaction simulation language, only information that describes the activities of the process from an equipment viewpoint (queue size, utilization, and service times, etc.) is automatically generated. Therefore the standard GPSS output as described in Appendix A is augmented by a matrix (51x17) that stores additional information about the process from a target viewpoint. The rows of the

matrix correspond to each transaction (target) in the order in which it is terminated. The information was maintained in selected parameters (see Appendix B) of each transaction and stored in the designated column of the matrix prior to termination. The information in each column of the output matrix is listed in Table III. The output matrix for the tenth replication of Case 2 is presented in Table IV as an example.

The statistics generated during the runs are analyzed in the next section in order to better understand the performance of the components of the battery gunnery team in surge situations. In Section IIIC the results of the simulation runs are utilized to evaluate the effects of the input factors on the system success as measured by the percentage of an enemy regiment (51 platoon elements) successfully engaged.

B. COMPONENT ANALYSIS

The program output was utilized to analyze each component of the battery gunnery team. The tabulated data supporting each result are included in Appendix E. Information in the tables includes an average over the ten replications ($\overline{X}$), a standard deviation (SD), and a 95% confidence interval based upon a t-distribution at $\alpha = 0.05$ with nine degrees of freedom. In the following component performance evaluations, the results from the tenth replication of Case 2 are presented, since Case 2 represents the least desirable situation where

TABLE III: COLUMNS OF OUTPUT MATRIX

Col 1	Target number
Col 2	Initial target range
Col 3	Departure range of target
Col 4	Number of times target was acquired by FO
Col 5	Number of times FO requested fire on target
Col 6	Number of times FDC accepted the fire request
Col 7	Number of times FB engaged target
Col 8	Number of times the target was preempted at FO
Col 9	Number of times target became nonintervisible
Col 10	FO number of target
Col 11	Total time for FO acquisition and processing
Col 12	Total time for FO transmission
Col 13	Total time for FO adjustment
Col 14	Total time mission waits to be transmitted
Col 15	Total time in FDC/FB loop
Col 16	Total simulated nonintervisible time
Col 17	Total survival time

TABLE IV: SAMPLE OUTPUT MATRIX

ROW/COL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	2879	2620	1	1	1	1	0	0	3	466	111	122	0	801	0	1378
2	9	2592	1915	1	1	1	1	0	1	1	482	126	109	46	615	9	2005
3	2	3461	2542	1	1	1	2	0	0	2	466	137	106	103	1601	0	2305
4	34	2560	1687	2	1	1	1	1	0	3	687	135	0	43	628	0	2377
5	21	2641	916	4	1	0	0	3	3	1	561	131	0	344	0	415	3105
6	6	2539	1040	3	1	1	1	2	2	3	433	118	0	106	568	165	3490
7	7	2974	956	1	1	0	0	0	2	1	289	110	0	735	0	431	3631
8	37	2665	902	1	1	1	1	0	2	1	481	130	108	269	753	381	3173
9	25	2759	871	3	0	0	0	2	0	2	722	0	0	1231	0	0	3397
10	19	2883	931	0	0	0	0	0	4	1	0	0	0	0	0	563	3512
11	20	2978	996	2	0	0	0	2	3	3	106	0	0	0	0	465	3567
12	23	2637	1094	4	2	1	1	2	1	2	1127	251	94	304	582	38	3544
13	27	2939	962	2	0	0	0	1	1	3	270	0	0	0	0	94	3558
14	38	2800	903	2	0	0	0	2	0	2	374	0	0	0	0	0	3414
15	48	2622	745	3	2	0	0	1	1	2	562	268	0	405	0	338	3377
16	5	3137	881	0	0	0	0	0	0	2	0	0	0	0	0	0	4060
17	31	2932	908	0	0	0	0	0	0	2	0	0	0	0	0	0	3642
18	11	3134	935	0	0	0	0	0	0	2	0	0	0	0	0	0	3957
19	4	3303	992	2	0	0	0	2	0	3	528	0	0	0	0	0	4159
20	3	3155	799	4	1	0	0	2	2	1	985	136	0	230	0	423	4240
21	49	2937	974	0	0	0	0	0	2	1	0	0	0	0	0	559	3533
22	36	3005	1479	1	1	1	1	0	0	3	289	105	101	279	620	0	3750
23	12	3172	877	0	0	0	0	0	2	3	0	0	0	0	0	468	4130
24	30	2641	503	2	1	0	0	0	0	3	719	103	0	2247	0	0	3848
25	15	3048	728	1	0	0	0	0	0	2	271	0	0	0	0	0	4176
26	33	3053	894	0	0	0	0	0	0	2	0	0	0	0	0	0	3886
27	14	3299	948	0	0	0	0	0	1	3	0	0	0	0	0	135	4231
28	50	2870	816	1	0	0	0	1	2	1	236	0	0	0	0	413	3696
29	10	3292	820	1	0	0	0	0	0	3	285	0	0	0	0	0	4448
30	22	3258	885	0	0	0	0	0	0	3	0	0	0	0	0	0	4270
31	24	3261	910	0	0	0	0	0	0	3	0	0	0	0	0	0	4231
32	16	3190	1219	1	1	1	1	0	1	1	259	116	96	82	628	88	4373
33	13	3396	939	0	0	0	0	0	0	1	0	0	0	0	0	0	4422
34	44	3133	948	0	0	0	0	0	0	1	0	0	0	0	0	0	3932
35	18	3171	723	1	0	0	0	0	0	2	271	0	0	0	0	0	4406
36	8	3487	958	0	0	0	0	0	0	2	0	0	0	0	0	0	4552
37	28	3326	962	0	0	0	0	0	0	2	0	0	0	0	0	0	4255
38	40	3302	988	0	0	0	0	0	1	2	0	0	0	0	0	102	4165
39	45	3253	976	0	0	0	0	0	3	2	0	0	0	0	0	119	4097
40	29	3402	959	0	0	0	0	0	1	1	0	0	0	0	0	218	4193
41	35	3327	936	0	0	0	0	0	1	2	0	0	0	0	0	171	4303
42	43	3056	726	1	0	0	0	0	0	3	263	0	0	0	0	0	4193
43	39	3278	914	0	0	0	0	0	1	3	0	0	0	0	0	31	4255
44	17	3495	937	0	0	0	0	0	0	3	0	0	0	0	0	0	4603
45	41	3119	763	3	0	0	0	2	0	1	480	0	0	0	0	0	4240
46	26	3413	915	0	0	0	0	0	1	1	0	0	0	0	0	267	4495
47	42	3095	701	1	0	0	0	0	0	2	297	0	0	0	0	0	4308
48	46	3226	783	1	0	0	0	0	0	3	267	0	0	0	0	0	4397
49	47	3350	884	1	0	0	0	0	0	1	284	0	0	0	0	0	4438
50	32	3473	724	1	0	0	0	0	1	1	286	0	0	0	0	153	4947
51	51	3430	888	0	0	0	0	0	1	1	0	0	0	0	0	307	4575

the forward observers have failed to detect the high speed attack until the enemy has advanced to within 3000 meters of the FEBA.

1. Forward Observer (FO)

The most utilized element of the gunnery team was the FO at 93%. Since the FDC was prohibited from allowing a queue to develop, all but two targets currently being processed at the FDC were in one of three states at the FO stations (never processed; previously processed but not current; processed and current). Therefore a significant portion of the FO utilization was accounted for in the acquisition and initial processing made.

The average utilization for one of the three FO's over the ten replications was not significantly different from the other two in any of the scenarios. Therefore the analysis of the times required by the FO to complete each of his three services was conducted for a "composite" FO. Columns 11-13 of the output matrix in Table IV give the total time each target consumed in each of the FO service modes prior to termination. For Case 2 the average portion of FO utilization devoted to processing and acquisition over ten replications was 81%, compared to 13% to transmit and only 5% to adjust the rounds fired. (See Tables E-I to E-VIII)

2. Fire Direction Net (FD Net)

The FD Net utilization is calculated from the sum of Columns 12 and 13 of Table IV divided by the total simulated

time. This calculation is equivalent to the sum of the average portion of time for each FO to transmit and adjust. For Case 2 the utilization was 54%. No simulated time is apportioned to the notification message, "SHOT", that the FDC sends to the FO after each mission is fired. In this replication of Case 2 this message was sent six times. The remaining number of messages sent is the sum of the entries in Column 5 of Table IV.

3. Fire Direction Center (FDC)

The FDC operated on the average in Case 2 at 67% of capacity throughout the simulated battles. Since the maximum number of missions capable of simultaneous FDC processing is two, the average number of computers in operation was 1.35. The number of fire missions is obtained from the sum of the entries in Column 6 of the output matrix in Table IV. In Case 2 the average ratio of the number of fire missions to the number of successful engagements was 1.1. This information is obtained from Columns 2 and 6 in Table IV. The average time between fire missions was 57.2 seconds and 63.6 seconds between successful engagements. (See Tables E-IX to E-XVII)

4. Firing Battery (FB)

The average utilization of the firing battery was the least of the gunnery team at 51.5% for Case 2. Since the FDC capacity is two missions and has no queue, the maximum FB queue length is constrained to one. Therefore

two successful services in tandem for the FB are followed by idle time until the next data are received. The number of battery volleys is obtained from the sum of the entries in Column 7 of the output matrix in Table IV. The corresponding ratios of battery volleys to fire missions and successful engagements was 1.1 and 1.2 respectively. These ratios are obtained from Columns 2, 6, and 7 in Table IV. The time between rounds fired was 51.5 seconds in Case 2. (See Tables E-IX to E-XVII)

5. Scenario Effects on Component Statistics

In each scenario a rapid buildup of queues at each FO was observed. Once the simulation of the beginning of the regimental attack was completed, the target flow from the GENERATE blocks was terminated, and the battery serviced as many targets as possible before the last target reached the 1000 meter no fire line. Therefore the utilization of each component in the most desirable situation (Case 7) is compared to the results of the worst case (lines 1-6 of Table V) in order to demonstrate the relative invariance of the individual component statistics across all eight cases. The overlapping confidence intervals and small standard deviations of the samples in each scenario support the conjecture that the utilization of each component is unaffected by the situation. The variations in component performance as measured by the ratios of the number of component services to the number of system services as shown in lines 7-9 of Table V are also not significantly different from one another.

TABLE V: COMPARISONS OF MAJOR COMPONENT STATISTICS (CASE 2 vs CASE 7)

	Case 2			Case 7		
	$\bar{X}$	SD	95% CI	$\bar{X}$	SD	95% CI
FDC Avg. Capacity	.669	.05	[.56;.78]	.777	.05	[.67;.89]
FB Utilization	.515	.03	[.44;.59]	.555	.04	[.47;.64]
FO Utilization	.927	.07	[.762;1.000]	.891	.09	[.694;1.000]
% FO Time Acquisition	81.39	1.01	[79.1;83.7]	79.22	.96	[77.1;81.4]
% FO Time Transmission	13.33	1.04	[11.0;15.7]	15.21	.56	[13.9;16.5]
% FO Time Adjustment	5.28	.64	[3.84;6.72]	5.57	.55	[4.33;6.81]
Ratio FM to Targets	1.12	.09	[1.00;1.32]	1.03	.02	[1.00;1.08]
Ratio Volley to Targets	1.25	.13	[1.26;2.54]	1.72	.12	[1.43;2.00]
Ratio FO Requests to Targets	1.90	.28	[1.26;2.54]	1.72	.12	[1.43;2.00]

The changes in system performance as described in the next section, must be attributable to the effects of the variable factors in each scenario and not on the changes in the individual components.

C. UTILIZATION OF THE SIMULATION RESULTS

The results of the battery simulation in the eight different cases described in the previous section were utilized in a 2^3 complete factorial experiment. Each of the eight scenarios correspond to a distinct combination of the three control variables, called factors, which are present at only two levels (high and low).

The purpose of the experiment was to analyze the main effects and interactions of target speed, initial intervisibility range, and target interarrival rate on the number of targets that the battery could successfully engage in surge situations. Table VI is a cross reference of case numbers and factor levels. The values for factors A and C represent a spectrum of different feasible combat situations and the values of factor B define the surge situations.

The number of targets serviced by the battery in each of ten replications of each scenario is given in Table VII. Each block number corresponds to a different scenario. The symbols 1,a,b,...,abc are used as an alternate scheme of identifying the different scenarios and are explained later in this section.

A graph of the estimated variance, S_i^2, of the response in each scenario plotted against the estimated mean, $\bar{X}_i$, is given in Figure 2. A regression line of the form $y = bx + a$ was computed by the method of least squares using the data in Table VIII. The value of the slope, $b = .07$, indicated

TABLE VI: CROSS REFERENCE OF FACTOR COMBINATIONS

SCENARIO/BLK #	FACTOR A RANGE INITIALLY INTERVISIBLE (meters) HIGH	LOW	FACTOR B TARGET INTERARRIVAL TIME (secs) HIGH	LOW	FACTOR C TARGET SPEED (kmph) HIGH	LOW
1		3000		5		10
2		3000		5	20	
3	5500			5		10
4	5500			5	20	
5		3000	12.5			10
6		3000	12.5		20	
7	5500		12.5			10
8	5500		12.5		20	

Note: Factor C is a constant and factors A and B are means of uniformly distributed random variables.

TABLE VII: NUMBER OF TARGETS SERVICED SUCCESSFULLY IN EACH SCENARIO

	FACTOR C: LOW		FACTOR C: HIGH	
	FACTOR A: LOW	FACTOR A: HIGH	FACTOR A: LOW	FACTOR A: HIGH
FACTOR B: LOW	BLOCK 1 19 19 20 20 20 20 20 21 21 23 1 = 20.3	BLOCK 3 36 36 37 38 38 38 38 40 40 41 a = 38.2	BLOCK 2 7 7 8 8 9 9 9 10 11 11 c = 8.9	BLOCK 4 17 17 18 18 18 18 19 19 19 20 ac = 18.3
FACTOR B: HIGH	BLOCK 5 19 19 20 21 22 22 23 23 23 26 b = 21.8	BLOCK 7 36 36 37 37 38 39 39 40 42 42 ab = 38.6	BLOCK 6 9 11 11 11 12 13 13 13 14 14 bc = 12.1	BLOCK 8 18 19 19 20 21 21 22 22 22 22 abc = 20.6

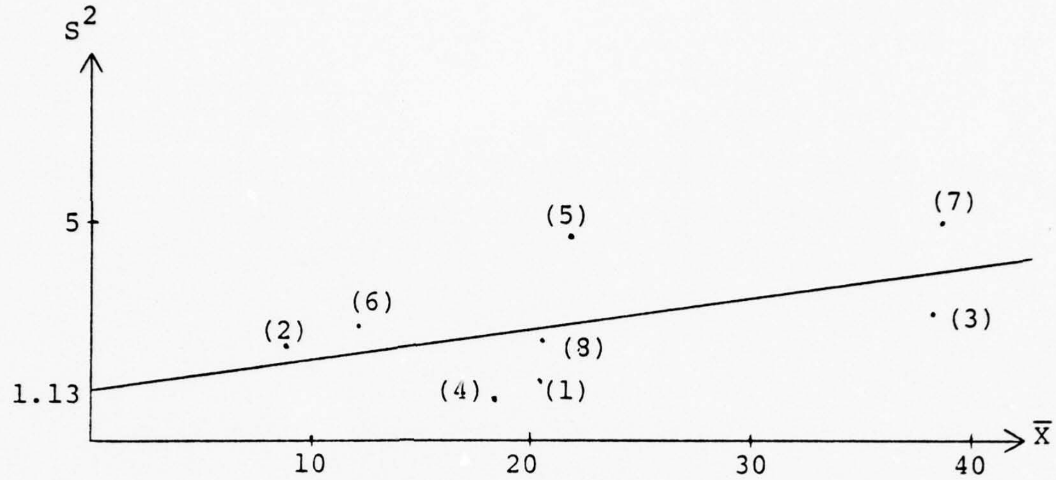

Figure 2. Graph of estimated treatment means $\overline{X}_i$ against estimated variances S_i^2.

TABLE VIII: MEAN RESPONSE AND STANDARD DEVIATION OF NUMBER OF TARGETS SERVICED

Scenario	$\overline{X}$	S^2
1	20.3	1.34
2	8.9	2.10
3	38.2	2.84
4	18.3	0.90
5	21.8	4.62
6	12.1	2.54
7	38.6	4.90
8	20.6	2.27

that the underlying variance was essentially constant over the range of values for $\overline{X}_i$. Therefore the analysis of variance was conducted using the original response data as presented in Table VIII. No variance stabilizing transformation was applied.

The blocks of Table VII have been labeled 1,a,b,ab,c, ac,bc,abc to facilitate the calculations of the estimated main effects and interactions of the factors A, B, and C. For example, the letter "a" represents the mean of the treatment where only factor A is present at the high level. The letters "bc" represents the mean for the case when both factors B and C are present at the high level. The number "1" indicates the treatment where all factors are at the low level. Since each factor occurred only at two levels, the estimated main effect for each factor was the difference of the mean for all treatments with one factor at the high level and the mean for all treatments which included that factor at the low level. For example, $\hat{A}$ is defined as the estimated main effect of Factor A and is given by

$$\hat{A} = \frac{1}{4}(abc + ab + ac + a - bc - b - c - 1). \quad (1)$$

The factoring of (1) yields

$$\hat{A} = \frac{1}{4}(a-1)(b+1)(c+1) \quad (2)$$

Substitution of the values from Table VII in (1) shows

$$\hat{A} = \frac{1}{4}(20.6 + 38.6 + 6 + 18.3 + 38.2 - 12.1 - 8.9 - 21.8 - 20.3)$$

$$= 13.15 \qquad (3)$$

The interpretation of $\hat{A}$ is that the number of targets serviced in all early warning situations was on the average approximately 13 targets more than those engaged in all scenarios where the detection was later (i.e. at a closer range).

The relation given in (2) is not the computational form but merely a mnemonic for that form given in (1). If the mnemonic expression is expanded in the algebraic sense, the correct computational form is obtained. This relationship generalizes for all estimated main effects and interactions as presented in Table IX.

TABLE IX: ESTIMATED MAIN EFFECTS AND INTERACTIONS

Factor	Mnemonic	Effect
$\hat{A}$	1/4(a-1)(b+1)(c+1)	13.15
$\hat{B}$	1/4(a+1)(b-1)(c+1)	1.85
$\hat{C}$	1/4(a+1)(b+1)(c-1)	-14.75
$\hat{AB}$	1/4(a-1)(b-1)(c+1)	- 0.50
$\hat{AC}$	1/4(a-1)(b+1)(c-1)	- 4.2
$\hat{BC}$	1/4(a+1)(b-1)(c-1)	0.90
$\hat{ABC}$	1/4(a-1)(b-1)(c-1)	0.05

The results indicate only a slight increase in the number of targets serviced when the times between arrivals (factor B) was at the high level. The magnitudes of the main effects of speed and range were approximately equal but of different sign which indicated a marked decrease in the number of targets serviced when traveling at the high speed level. None of the interactions were of the same order of magnitude as the main effects of A and C.

In order to determine whether any main effect or interaction was significant, hypothesis testing was conducted. The complete argument is presented for $\hat{A}$. The procedure for examining the remaining main effects and interactions is analogous.

Since $\hat{A}$ in (1) is the difference of estimated means, the variance of $\hat{A}$ is given as follows:

$$\mathrm{Var}(\hat{A}) \quad = \quad \mathrm{Var}[\tfrac{1}{4}(abc+ac+ab+a-bc-b-c-1)] \qquad (4)$$

Because each treatment is independent the expression in (4) becomes

$$\mathrm{Var}(\hat{A}) \quad = \quad 1/16[\sigma^2/k+\ldots+\sigma^2/k] \qquad (5)$$

where σ^2/k is the variance of each treatment mean, σ^2 is the underlying population variance and k is the number of replications.

In the 2^n factorial designs the variance of $\hat{A}$ in (5) becomes

$$\mathrm{Var}(\hat{A}) = \left(\frac{1}{2^{n-1}}\right)^2 \left(\frac{\sigma^2 2^n}{k}\right) \tag{6}$$

For the experiment in this thesis for $n = 3$ and $k = 10$ (6) is evaluated as

$$\mathrm{Var}(\hat{A}) = \frac{\sigma^2}{20} \tag{7}$$

It can be shown that the unbiased estimate of σ^2 is the error mean square (EMS) in the analysis of variance [Ref. 1]. Therefore the estimated variance of $\hat{A}$ is given by

$$\mathrm{Var}(\hat{A}) = \mathrm{EMS}/20 \tag{8}$$

Since EMS is a Chi-square random variable, the error sum of squares (ESS), from the analysis of variance, divided by its degrees of freedom, $\hat{A}/\sqrt{\frac{\mathrm{EMS}}{20}}$, has a t-distribution with f degrees of freedom. (The degrees of freedom of ESS equal f). The square of a t-distributed random variable has an F-distribution with 1 and f degrees of freedom. That is $\frac{20\hat{A}^2}{\mathrm{EMS}}$ has an F-distribution. It can also be shown that the treatment sum of squares attributable to the main effect of A (ASS) is given by

$$ASS = 20\hat{A}^2 . \tag{9}$$

The hypothesis that the main effect of factor A is zero is rejected at level α if

$$\frac{ASS}{EMS} = \frac{20\hat{A}^2}{EMS} > F_f^1(1 - \alpha) . \tag{10}$$

The complete analysis of variance for the results obtained from the simulation runs is given in Table X. At the $\alpha = 0.05$ level the main effects of factors A and C are significantly different from zero. Additionally the main effect of B and the AC and BC interactions are significant. Other interactions are not significant.

TABLE X: ANALYSIS OF VARIANCE

Source	Degrees of Freedom	Sum of Squares	Mean Square	Test Statistic
Total	79	8446.20	106.91	N/A
Treatment	7	8252.50	1178.885	N/A
Factor A	1	3458.45	3458.45	1285.5
Factor B	1	68.45	68.45	25.4
Factor C	1	4351.25	4351.25	1617.4
AB Interaction	1	5.0	5.0	1.9
AC Interaction	1	352.8	352.8	131.1
BC Interaction	1	16.2	16.2	6.0
ABC Interaction	1	.05	.05	0.0
Error	72	193.7	2.69	N/A

The results of this experiment are described below.

1. The longer a target was in the system, the more likely it would be engaged. This situation was produced by increasing detection range or decreasing target speed.

2. The larger the interval between target arrivals, the higher the percentage of successful engagements. However, when the interarrival times were large in comparison with the service times, a surge situation never developed. Therefore since the effect of factor B (indicated in Figure 3 by the relatively horizontal line) was only a fraction of that for factors A and C, the remaining analysis was conducted on the effects of A and C averaged over the values of factor B. For example, the case describing the average over the values of factor B for long range (early detection) and slow target speed is referred to as Case 3,7.

Figure 4 shows the relationship between the artillery battery success (percentage of an enemy regiment engaged) as a function of FO detection range for different attack speeds. For example, in order to engage 60% of the regiment traveling at 10 kmph the FO must be aware of the attack on the average of 4500 meters in front of the FEBA. On the other hand if a regiment moving at 20 kmph is first detected at only 4500 meters, less than 30% will be engaged by the battery. The curves in Figure 4 are not parallel since there was an interaction between target speed and detection range which indicated that the effect of range changes were

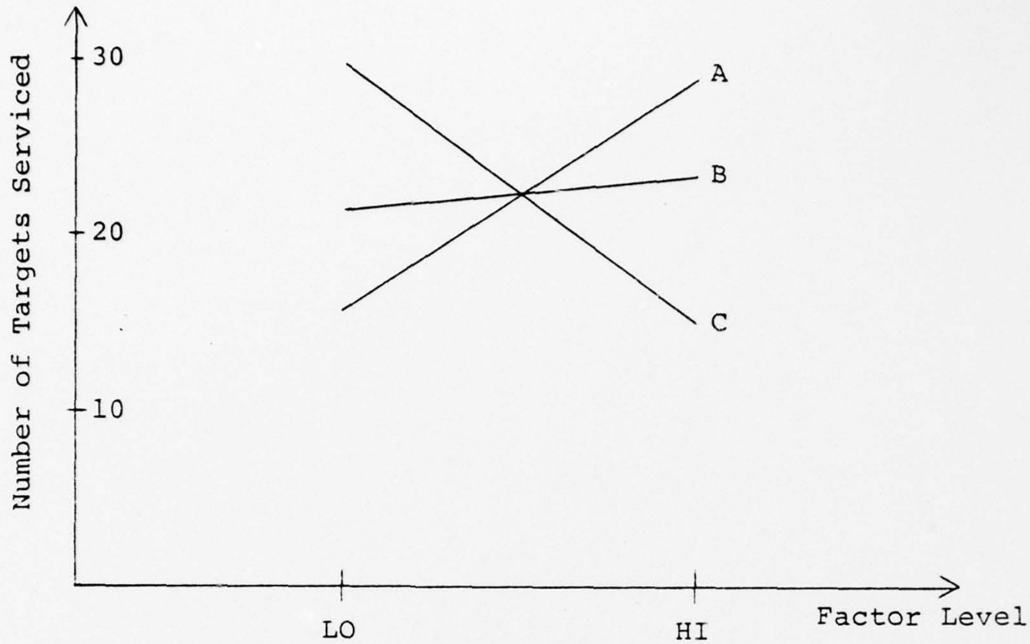

Figure 3. Graph of Factor Main Effects

different for each speed. The dotted extensions of the speed curves are extrapolations of the results indicating the reduced effectiveness of the battery as a function of the loss of detection capability.

Successful engagement as previously defined implied that target range at the beginning of a service was immaterial provided that it was beyond 1000 meters from the FEBA. Figure 5 shows the cumulative percentage of a regiment serviced at each 200 meter range interval as a step function for each of the four cases. For example, if the anticipated enemy threat were less mobilized and infantry heavy as opposed to armor, the success of the artillery in Case 1,5 is better than that in Case 4,8. That is, the advantage

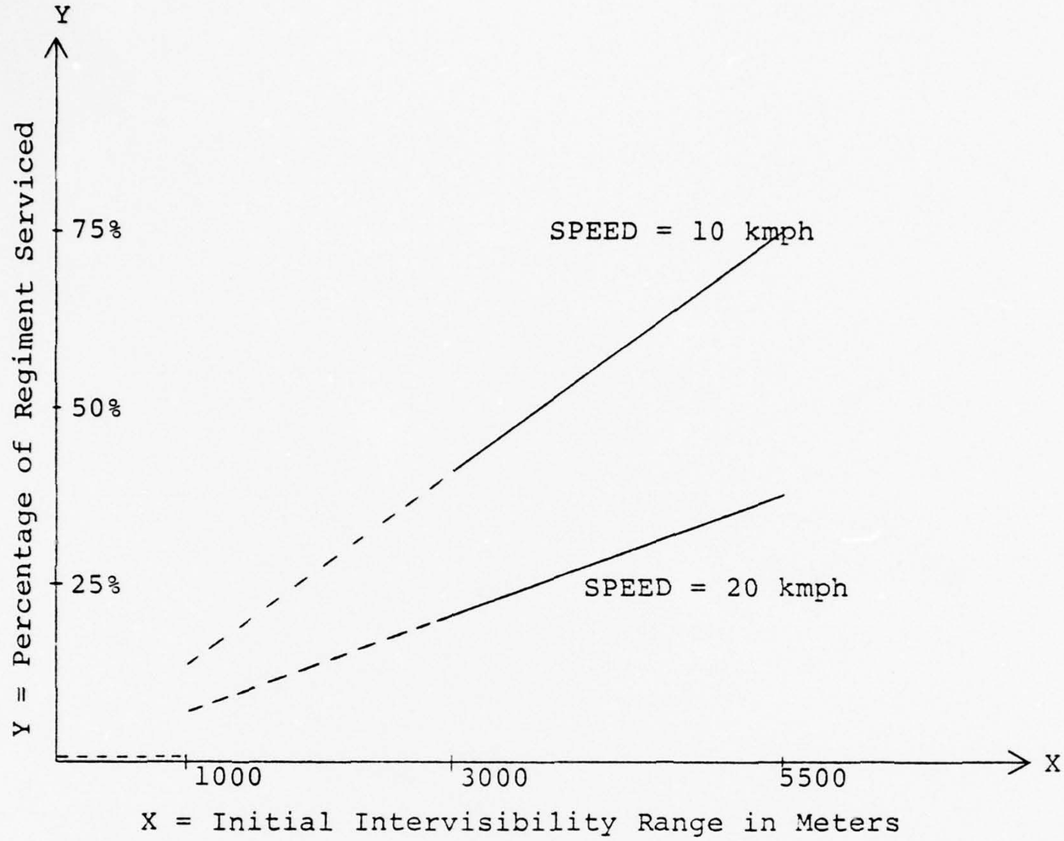

Figure 4. Graph of Contrasts of Detection Range and Speed on Artillery Success

of early detection represented by the higher percentage of distant service ranges is not significant from a military worth point of view since the threat from an infantry platoon does not increase appreciably in the 1000-5000 meter range. The situation would be entirely different however if the enemy force were predominately armor. The threat from a tank platoon would increase quite significantly at ranges

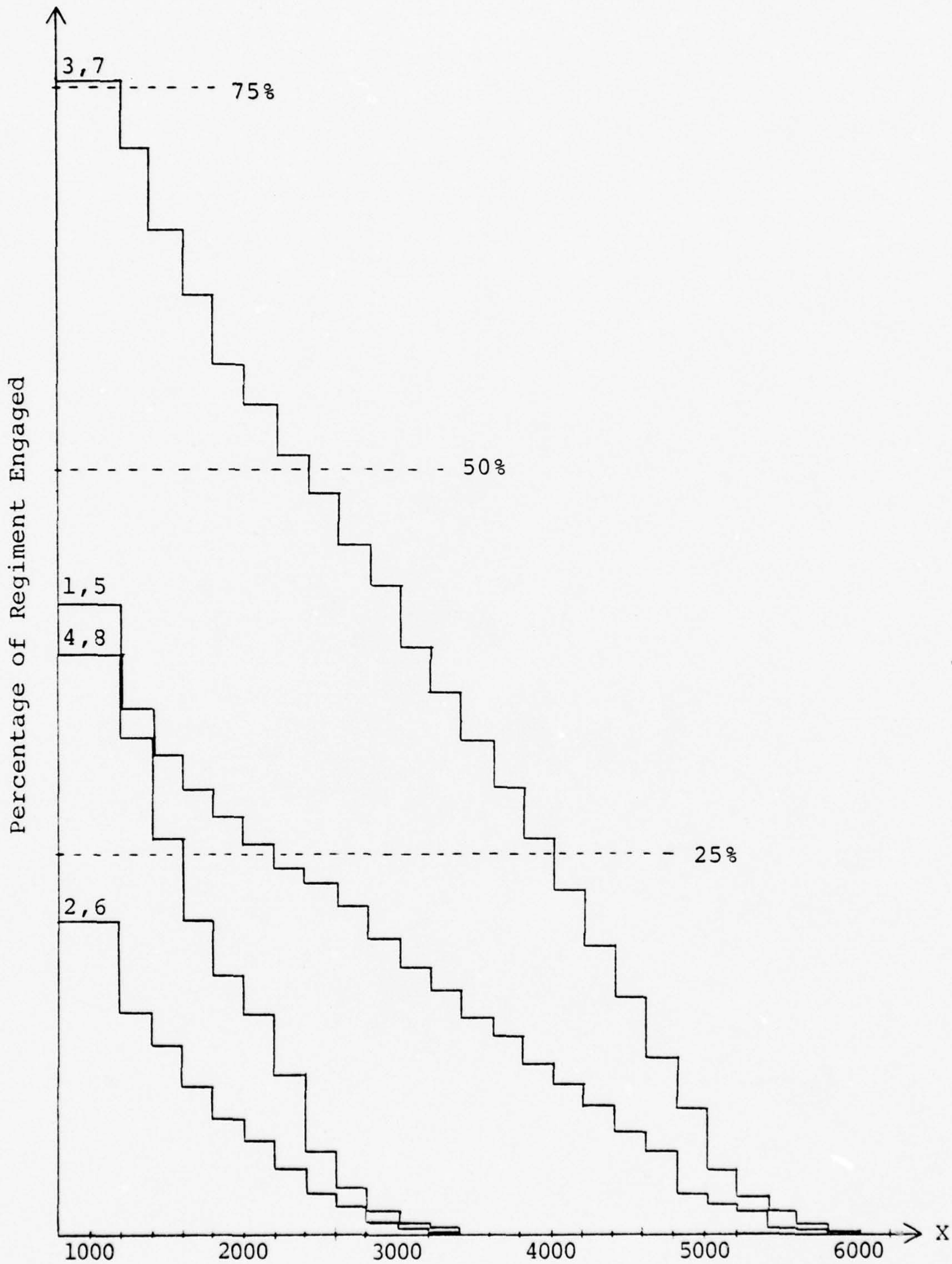

Figure 5. Percentage of Regiment Engaged at Range X (meters)

within 3000 meters of the FEBA. In Case 4,8 almost 20% of the regiment was engaged beyond 3000 meters and 25% had been engaged by the 2200 meter mark as opposed to the corresponding 7% and 10% levels achieved in Case 1,5. To illustrate this difference more dramatically, Figure 6 was included to show the percentage of targets serviced at each range level of those targets successfully engaged. A table of values from which Figure 5 and Figure 6 were obtained is included in Appendix E. (See Table E-XVIII.)

As described in Section IIIB, the statistics of service components of the artillery battery (FO, FDC, and FB) are not significantly different in each of the eight scenarios. However, system service times (obtained from column 17 of the output matrix in each scenario) for successfully engaged targets were generally increasing and of comparable magnitudes within the limits of total targets serviced in the different cases. To illustrate the relationship between the total time in the system and the number of the target serviced, the average time of the n^{th} departure in the four composite scenarios was calculated and paired to the corresponding percentage of the total regiment. The resulting regression curves are shown in Figure 7. The number of points used, the function, and the value of R^2 for the curves in Figure 7 are given in Table XI. The extremely high values of R^2 in Table IX indicated the relationships between average service times and target number are linear.

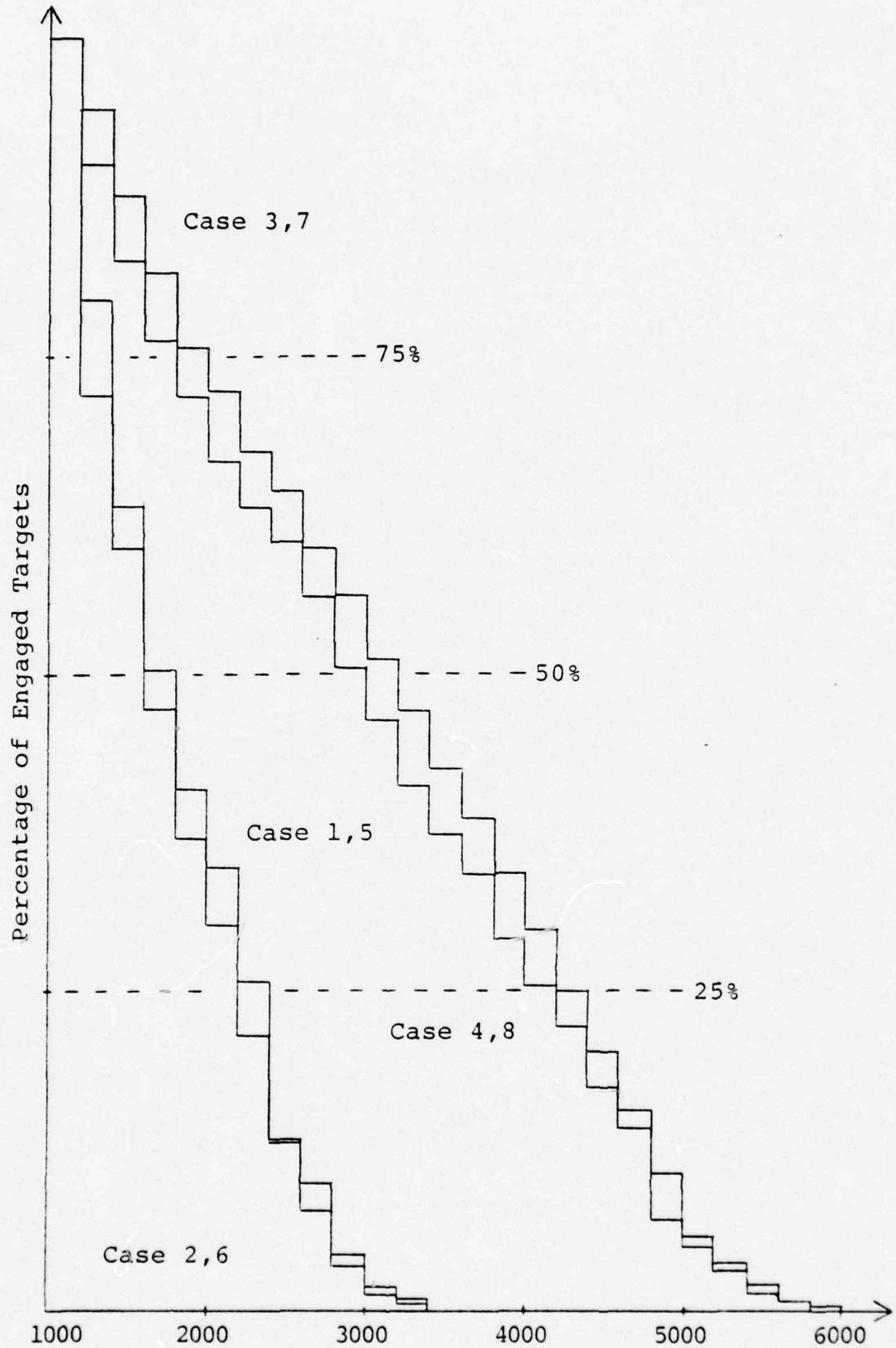

Figure 6. Percentage of Engaged Targets Serviced at Range X (meters)

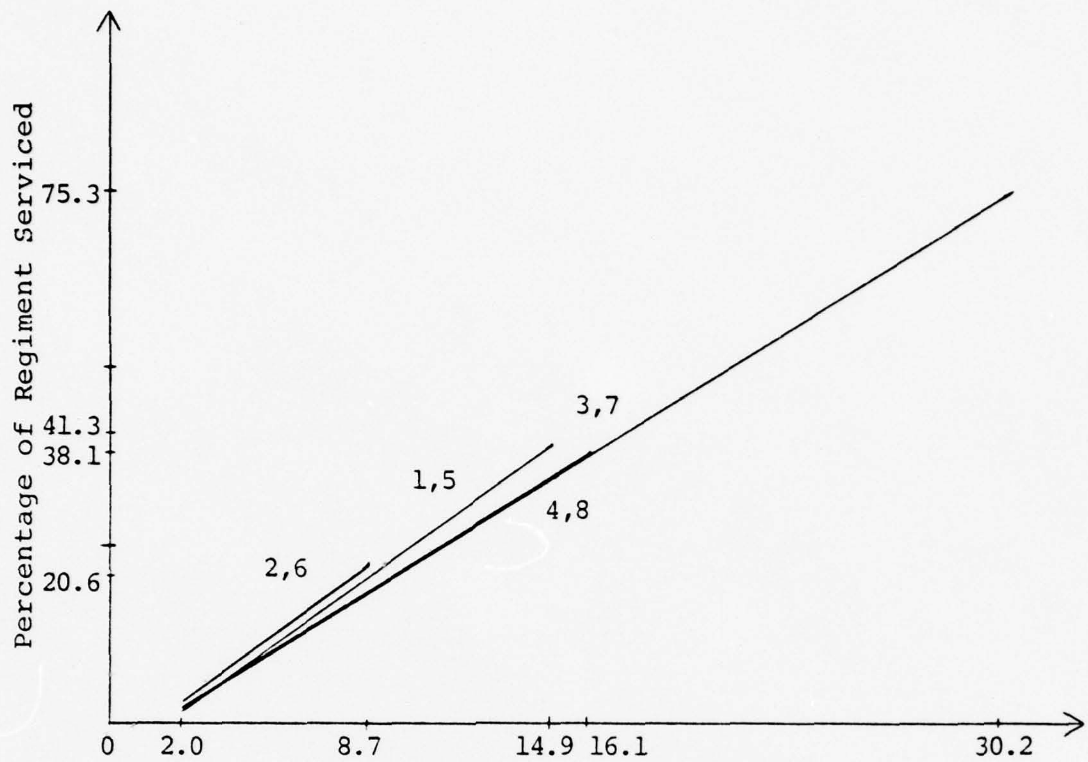

Figure 7. Regression Plots of Service Times (min)

TABLE XI: REGRESSION RESULTS FOR TARGET TRANSIT TIMES

Case	n	function	R^2
2,6	14	y = 3.10x - 4.77	0.990
1,5	21	y = 3.04x - 5.54	0.980
4,8	22	y = 2.70x - 5.15	0.996
3,7	42	y = 2.63 - 4.50	0.998

Note: The data points used to compute the regression curves are found in Table E-XIX.

This implies that the departure rate from the queuing process defined by the battery gunnery team is essentially constant. Since all targets arrive in each FO zone by the time the first target is successfully serviced, each target has accumulated approximately equal total time in the system prior to the beginning of the combined FDC/FB service. This combined service does not vary considerably from one target to the next, since its distribution is the sum of two uniform random variables each of which is distributed over an interval of five seconds. The constant departure rate, therefore, corresponds to the differences in total time in the system between two successive departures which are produced by that portion of the combined FDC/FB service that does not occur simultaneously.

IV. RECOMMENDED FUTURE APPLICATIONS

A. GENERAL APPLICATIONS

Systems simulation in general can be applied to the two different areas: improvement of existing systems; and the development of new ones. A computer model of an existing system can be used to evaluate performance under actual or test conditions. Computer simulations can also be employed to evaluate the effectiveness of new designs from a cost effectiveness viewpoint without building expensive physical models.

System performance in both existing and proposed designs can be tested under a variety of conditions by using the scenario concept in developing simulation runs. The results of the simulation can then be analyzed to ascertain the significance of different factors in the scenarios on the mission. Scenarios developed in this thesis portrayed different surge conditions that could arise in combat situations. Scenarios of this type portray hypothetical situations where the analyst is not sure what the system service environment will be but wants to be certain to bracket the realm of likely situations. Under these situations a 2^n factorial experiment is often an appropriate method of analysis.

Identifying bottlenecks in a service configuration such as the battery fire support system is the first step

in recommending procedures or introducing new hardware to alleviate the condition. The analysis of equipment statistics through simulation can demonstrate how the overall mission service time changes with respect to different values for intermediate processing at individual stations. For example, simulation runs of the battery identified bottlenecks at the FDC. By the early 1960's the gun direction computer M18 (FADAC) was introduced into the battery FDC and the FDC processing time was reduced. Such a modification of the system could have been simulated by changing the distribution for FDC service time. The contrasts of the system performance would have been tested for significant differences. The ultimate adoption of FADAC would then have been confirmed after a cost effectiveness analysis had been performed to weigh the decreased computation time and the concomitant savings on the battlefield against the cost of installing the FADAC in each battery FDC.

One of the newest developments in the field artillery is the TACFIRE system which would reduce not only FDC computation below the rate of FADAC but will virtually eliminate communications time from the FO through the FDC to the FB. The TACFIRE system could also be simulated by the model presented in this thesis.

In view of the imminent adoption of the TACFIRE system reasonable questions to ask would include:

1. where will the bottlenecks develop in the gunnery chain now?

2. what is the cost effective number of observers and batteries that can be integrated into a TACFIRE system?

3. what personnel are still necessary as a backup in the FDC to sustain a specified level of system reliability? The model described in this thesis, appropriately modified, could be useful in answering the above and similar questions that will arise in field artillery fire support system modification and design.

B. ENHANCEMENT OF CURRENT MODEL

The capabilities of GPSS lend themselves to further sophistication of the model as presented here. The author envisions future research that will address certain limitations in the present model as described below.

1. Detection Submodel

The detection submodel described in this thesis has been built upon the assumption that if a target was intervisible, the FO detected it and was able to request fire on it no matter how long the target remained intervisible. The FO always reported a platoon no matter what portion of the target was intervisible. An improvement upon the current model should include a detection function as well as a method to determine target size and composition based upon that portion of the target that was observed.

2. FO Target Selection Priority Scheme

The priority scheme in this model was target range and was discussed in the modeling assumptions. A higher

resolution detection submodel should include a more sophisticated priority scheme. Such a scheme should take into account, in addition to target range, target type (APC, tank, etc.), whether or not the target is moving, and if the target is firing, is it already being fired upon by friendly direct fire weapons. In Ref. 10 additional criteria in developing priority schemes based upon the military worth of the target are described.

3. Fire Effects Submodel

The procedure for evaluating the effectiveness of the artillery fire in the model as presented here has been purely subjective in nature. If the total battery service time was less than the standard in Ref. 2, the mission was considered successful and the target was removed. Success in engaging moving armored targets as defined earlier did not include level of damage or casualties but only that a portion of the attacking force was disrupted. The model currently only differentiates targets that leave the system as effectively serviced or uneffected by artillery fire. An improvement on this model should incorporate a fire effects submodel capable of objectively assessing the success of the artillery fire.

4. Asset Availability

It has also been assumed that ammunition (projectile and fuse) types and quantity have always been available, that all of six howitzers have been in serviceable condition

when needed, and that each fire mission required only one round per gun to be fired. An improved fire effects sub-model would require asset availability to be simulated in the FDC evaluation process in decision 3. as described in Section IIB.

C. TOPICS FOR FUTURE INVESTIGATION

Simulation models have been previously constructed to model selected types of fire support systems. Some examples are computer simulation models of Marine Amphibious Force and LEGAL MIX/REDLEG PROCESSES [Ref. 7] and [Ref. 11]. It has been the intent of this thesis to present a basic program model that accurately simulates the field artillery gunnery team by component as well as an entire system. Although only the activities of one battery have been simulated, the format for expanding the model to handle an entire battalion and concomitant activities has been developed in part through the indirect addressing capability of GPSS. The model may be further utilized to identify those areas where modern technology may be applied to improve system performance. An abbreviated analysis of the effects of target speed and range on artillery success in a complete factorial design experiment was presented to further demonstrate the analytical capabilities of the model.

The analysis of the FO, FDC, and FB indicate the potential usefulness of the model. A more extensive analysis

should be conducted in the FDC and FB. A further break-down of these facilities to include individuals such as the computer, fire direction officer. the howitzer section chief, and individual cannoneers could provide more detailed insight as to how the human interface with the fire support system reacts under stress. For example, the relationship between the level of individual training and accuracy of fire in a high-threat environment when the artillerymen are concentrating on speed could be investigated.

The possibility that future projects and data collection efforts will reveal different underlying distributions of processing times than the ones described in this thesis does not reduce the model credibility, but will in fact increase its utility. The versatility of the model is dependent only upon the analyst's knowledge of GPSS, computer resources, and the data which is incorporated into it.

It is the belief of the author that the model may serve as an analytical tool in assisting research efforts to insure that the United States Army Field Artillery continues to accomplish its mission, <u>Celeritas et Accuratio</u>.[1]

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[1]Third Battalion, Third Field Artillery Regiment, Motto, "Speed and Accuracy", 1847.

APPENDIX A: DESCRIPTION OF GPSS

The General Purpose Simulation System (GPSS) is one of the oldest discrete simulation languages. There have been many versions of GPSS. The system in operation at the Computer Facility, the Naval Postgraduate School, Monterey, California is GPSSV. The design of GPSS is based upon the assumption that systems can be simulated adequately through dynamic entities, equipment entities, statistical entities, and operational entities.

The dynamic entities are transactions. They are created and destroyed during the course of the simulation. Transactions are fully defined by parameters. Activities are created by the interaction of transactions on the other types of entities.

Equipment entities simulate items of equipment. Two basic types of equipments are available in GPSS: the facility entity which is capable of handling at most one transaction; the storage entity which represents servicing stations which simultaneously process several transactions. These two entities may be combined as necessary to produce the desired service configuration.

Several statistical entities, including queues, chains, tables, and graphs are available to analyze the system. Queues and chains measure the contention for use of the equipment entities by the transactions. All possible

queuing disciplines (priority, first-in first-out (FIFO), LIFO, and random selection) can be developed.

The operational entities of GPSS are called blocks. Each block is in effect a subroutine, and together they determine the logic of the system by controlling the flow and interaction of transactions. The GENERATE and TERMINATE blocks control the "birth and death" of transactions. The ASSIGN block ascribes or modifies the attributes of each transaction entering the block through changes in the parameters. The SEIZE and RELEASE blocks simulate the use of the facility. The ENTER and LEAVE blocks perform the analogous functions for a storage. The QUEUE and DEPART; LINK and UNLINK blocks quantify and control bottlenecks where waiting lines build up. The LINK block has the additional capability of removing the transactions from the GPSS scan until the UNLINK block is encountered. This shortens the computer run times which may easily become excessive in simulating large systems. The ADVANCE block simulates time delays that transactions encounter as they move through the system. Normally the transaction currently being processed will be pushed along until one of three events occur:

1. a TERMINATE block is encountered;
2. an ADVANCE block;
3. or an obstruction at the next block is encountered because there is another transaction blocking the way. Thus

all transactions would proceed through the system in zero time without ADVANCE blocks. A system-wide clock is maintained in order to schedule and control the integration of transactions from the future events chain onto the current events chain. The clock is maintained in discrete units of time. The dimension of the unit is immaterial (decades to deciseconds).

GPSS also allows for the use of functions to define complex empirical as well as standard theroetical distributions. Computational variables to evaluate algebraic formulae involving various system/transaction attributes are also permitted but limited to addition, subtraction, multiplication, division, and modulo division. GPSS also provides eight random generators.

One of the most appealing features of GPSS is the program output which has been automatically developed throughout the course of the simulation run. With use of various program control cards any or all of the following information is accessible: transaction counts for all blocks; queue, facility, or storage statistics, including average utilization, maximum contents, total entries, average service/waiting times as well as average waiting times for those required to wait. Utilizing GRAPH, ENDGRAPH, and TABULATE statements, histograms and tables will be printed for the desired distribution, such as the distribution of transaction service times.

Numerous examples of GPSS simulations of different queuing models are given in Refs. 6 and 8. For a complete discussion of GPSS V see Ref. 5.

APPENDIX B: LIST OF GPSS TRANSACTION PARAMETERS

1. Byte Parameters

   PB1 - indicates target is nonintervisible if equal to 1, implying the target is not detected at this time.

2. Floating Point Parameter

   PL1 - The integer portion indicates what terrain band the target has moved into. The decimal portion is used to calculate expected time the target will become intervisible.

3. Half-Word Parameters

   PH1 - The enemy platoon identification number representing the order of arrival into the combat zone. Values include 1,...,51.

   PH2 - current range of the target measured in meters from the FEBA

   PH3 - identifies the FO zone in which the target is attacking.

   PH4 - stores the value for the length of time a target remains nonintervisible each time it is not located.

   PH5 - stores the position of the transaction relative to all other targets.

   PH6 - represents the FD net in which the call for fire pertaining to the transaction is being sent.

   10 - FD net for battery 1 (only one in current model)
   20 - FD net for battery 2
   30 - FD net for battery 3
   50 - FD net for the battalion

   PH7 - represents the FB that will fire the mission pertaining to the transaction.

   11 - FB for battery 1 (only one in current model)
   21 - FB for battery 2
   31 - FB for battery 3

PH8 - represents the queue of completed missions at each FO

4 - FO 1
5 - FO 2
6 - FO 3

PH9 - represents the FDC that will process the fire mission pertaining to the transaction

7 - FDC for battery 1 (only one in current model)
8 - FDC for battery 2
9 - FDC for battery 3
0 - Battalion FDC

PH10 - a three-digit random number the value of which determines the processing order in the FD net queue

PH11 - number of times the transaction began FO processing in target acquisition mode

PH12 - number of times the transaction was processed by the FDC

PH13 - number of times the transaction was processed (target was fired upon) by FB before it was eliminated

PH14 - initial range of the target measured in meters from the FEBA

PH15 - cumulative time a target was nonintervisible summed over each time it is not located

PH16 - number of times the transaction completed processing at the FD net

PH17 - number of times the transaction was preempted at the FO in the target acquisition mode

PH19 - number of times the transaction (target) was not located (was nonintervisible when the FO attempted to locate it)

PH20 - number of times the FB engaged the target during one processing cycle plus 1

PH21 - Truncated integer value of PB1 as defined above.

4. Full-Word Parameters

PF1 - holds current clock time for transactions that pass block MARK 1PF. Used in computing FD net service time.

PF2 - holds current clock time for transactions that pass MARK 2PF blocks. Used in updating target range.

PF3 - holds current clock time for transactions that pass MARK 3PF blocks. Used to compute time waiting to be transmitted to FDC.

PF4 - holds current clock time for transactions that pass MARK 4PF blocks. Used to compute combined FDC/FB and FO adjustment time.

PF5 - holds current clock time for transactions that pass MARK 5PF blocks. Used to compute FO adjustment time.

PF6 - contains FO fire mission processing time for each transaction.

PF7 - contains total time waiting to be transmitted per transaction.

PF8 - contains total combined FDC/FB/FO adjustment time per transaction.

PF9 - contains total system transit time for each transaction.

PF10 - contains total service time for the FO in transmitting each fire mission to the FDC.

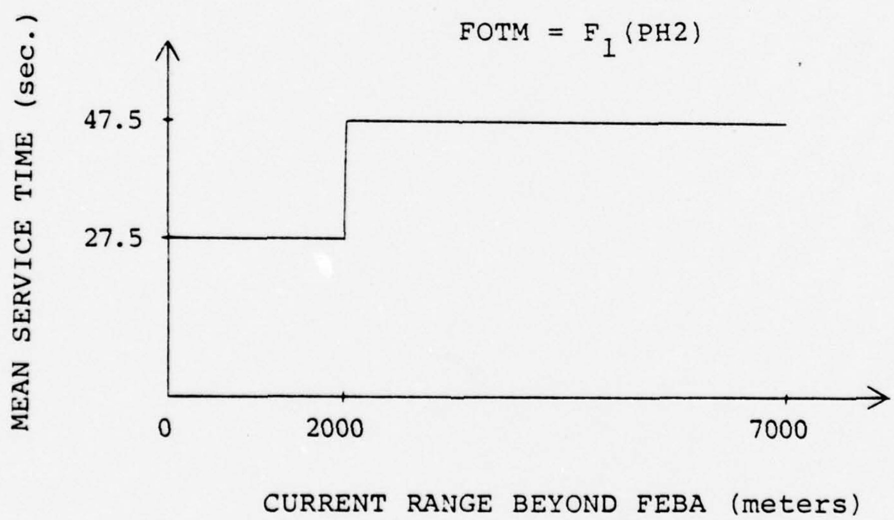
PF12 - contains total service time for the FO in the adjustment mode for each transaction.

PF15 - contains the clock time at which each transaction entered the model.

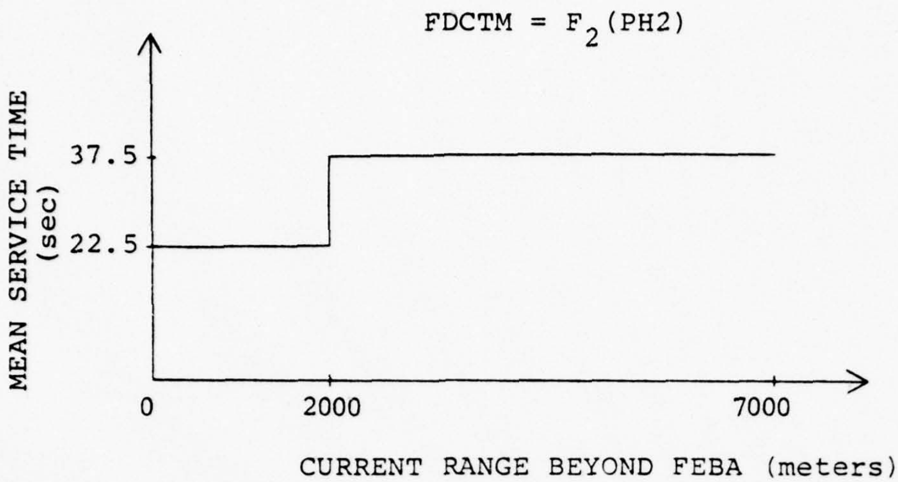
APPENDIX C LIST OF GPSS FUNCTIONS AND VARIABLES

FUNCTIONS

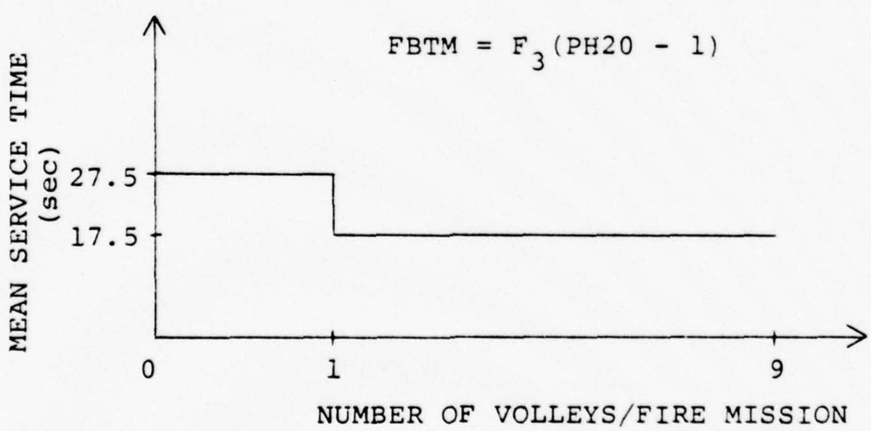
The following graphs depict the discrete and continuous functions assigned to the GPSS program for the simulation runs:



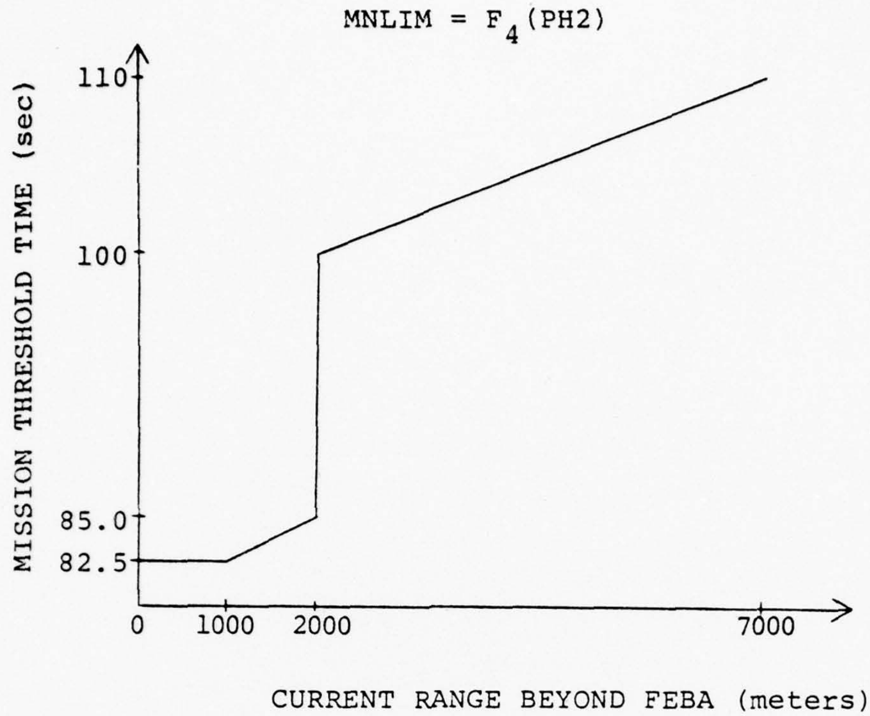
The average time for the FO to prepare a call for fire is 27.5 seconds for targets within 2000 meters of the FEBA and 47.5 seconds on the average beyond 2000 meters.



The mean time for the FDC to process a request for fire is 22.5 seconds based on the assumption that the requests are of an immediate nature and the targets are located within 2000 meters of the FEBA. Mean time is 37.5 seconds for targets at ranges beyond 2000 meters.



The average time for the FB to lay,load and fire the initial round in a fire mission is 27.5 seconds. The mean time for all subsequent rounds in that mission is 17.5 seconds.



The fire mission is considered successful if the elapsed time from when the FO began his call for fire to when the rounds impact on the requested location is less than the mission threshold times. Because of the variable time of flight, each engagement range has a different mission threshold.

VARIABLES

1. TOF = (PH2 + XH10)/54.

TOF calculates the time of flight where XH10 is the battery displacement behind the FEBA, and PH2 is the current target location forward of the FEBA. The horizontal component for the weapon muzzle velocity is 540 meters/second.

2. RGE = (XH7 - XH6)*RN4/1000. + XH6

RGE calculates the initial target location where XH7 is the maximum range and XH6 is the minimum range; RN4 is a three digit random number. The result is an initial target range that is distributed uniform U[XH7, XH6].

3. ORDER = PH14 + C1*XH9/36000.

ORDER calculates the priority by which targets are serviced in that it modifies the initial range to compensate for early and late arrival times.

4. MOVE = PH14 - MP15PF*XH9/36000.

MOVE calculates the distance that the target has traveled since the transaction passed through an MARK 15PF block. XH9 is the target speed in meters/hour. Target speed is converted to meters/decisecond by the factor 36000. MP15PF is the difference between the value stored in 15PF and the current clock time. PH14 is the initial target location.

5. NRSEG = MP15PF*XH9/XH2/36000.

NRSEG calculates the real valued number of visibility bands that the target has crossed since it entered the FO zone. XH2 is the length of all terrain bands in meters (both intervisible and non-intervisible).

6. INVIS = (PL1 - PH21)*XH2*36000/XH9

INVIS calculates the remaining time until a non-intervisible target becomes intervisible again.

7. MOD = PH21 mod 2

MOD equals 1 if PH21 is odd representing the non-intervisibility bands. If MOD is 0, then PH21 is even and corresponds to an intervisibility segment.

APPENDIX D: PROGRAM DESCRIPTION AND GPSS BLOCK DIAGRAM

The purpose of this appendix is to explain in more detail how specific GPSS operational blocks were combined in the program to simulate specific attributes of the battery gunnery team model as described in Section II. The complete block diagram with abridged commentary is also included in this appendix for additional reference.

The QUEUE-SEIZE(ENTER)-DEPART-ADVANCE-RELEASE(LEAVE) sequence of blocks was one method employed in the program to gather statistics on the facility (storage) utilization and queue waiting times at the FO, FD net, FDC, and FB. Combinations of ASSIGN and MARK blocks were used to count numbers of services and the total length of each service for every transaction that entered a particular service station. This information about the battery fire support system was consolidated with the help of MSAVEVALUE blocks into two matrices (51x10) and (51x7) for each run and scenario. The complete description of these matrices with examples was presented in Section III.

The GENERATE statements were used to introduce the targets into each FO zone. The scenarios in this model portrayed one enemy battalion consisting of 17 platoons attacking in each FO zone simultaneously. Other attack situations could be portrayed by changing the number of

the GENERATE blocks and altering a particular combination of the nine operands A-I in the Operand Field of the GENERATE block.

At the time that the enemy units were generated, transaction parameters were ASSIGNed to each target to describe such attributes as initial range, zone of action, target type, time in the system, etc. The indirect addressing capability of GPSS which requires the use of selected transaction parameters was an aid in reducing by one-third the blocks necessary to describe this model. Expansion of the current model to simulate an entire battalion would require only a small fraction of the blocks necessary without the indirect addressing capability. For example the two additional firing batteries require no additional blocks because the half-word parameter PH7 that defined the FB station with the value 11 in the current model could be allowed to take additional values such as 21 and 31 so that the block SEIZE PH7 would mean, the target is fired upon by the battery which is identified by the value of PH7 parameter of the target. A complete list of parameters used in this model with a short description is found in Appendix B.

User chains as opposed to the PRIORITY block were selected to simulate priority queue disciplines. In addition to adequately controlling the priority scheme, the use of the chains allows the program to run more rapidly. The priority scheme developed for this simulation was based on

range to the FEBA. Targets closer to the FEBA are engaged before those more distant. The LINK block placed transactions on a user chain in increasing value of the parameter specified with lower values ahead of higher values. The parameter PH5, current target range, was specified to control the queues that developed at each FO. Range to the FEBA priority scheme was not unrealistic under the assumptions of the model that all targets were platoons of different armored vehicles. At 5000 meters, identification of vehicle type and weapon system would at best be difficult. Unit operating procedure would determine the exact priority policy in specific situations.

The random selection discipline for the FD net queue was simulated by having selected a random number from RN3, the third random number generator, and having it placed in PH10. The mission was LINKed on a user chain that was ordered by PH10. After each transmission was completed a new number was drawn for each remaining mission in the queue.

The FDC simultaneously processed two fire missions on a FIFO basis. Other missions received while the FDC was full were refused entry by use of the TEST block and returned to the FO. Once again unit operating procedure would dictate what policy would be followed in the FDC for overload situations. Included in this policy would be considerations for maintaining an FDC queue; when to forward the overload to another battery; and which battery would accept overloads.

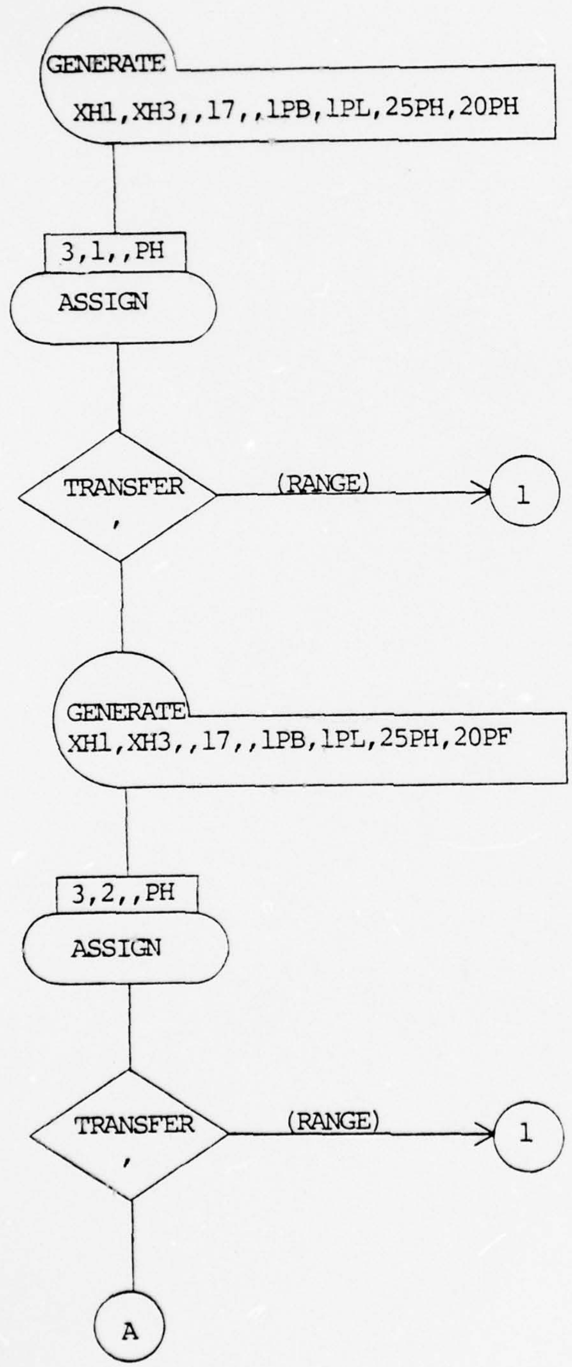
Since the FO's only had one battery available in this model, once each had his highest priority mission accepted by the FDC, he did not attempt to transmit another request. This procedure was simulated by placing UNLINK blocks for the FD net queue after the blocks for service termination at the FDC and FB.

The simulation of the FD net was accomplished with the use of the GATE, LOGIC R, LOGIC S blocks which test/alter the status of the GPSS entity, logic switch. Before each transmission, the logic condition of the switch indirectly addressed by PH6 was tested at the GATE block. If the net was open the condition on the GATE matched that of the switch and the message was transmitted. Once the transmission began the LOGIC S block closed the net to other traffic. Upon completion of the transmission the LOGIC R block was used to reopen the net.

PREEMPT-RETURN combinations were used to simulate those periods when the FO would renege on a target being serviced in acquisition (initial) mode, to transmit another request that was already completed or to adjust fire on rounds just fired into his zone. The FO was not permitted to conduct his three functions simultaneously. The program logic allowed the preempted target to be the first processed by the FO when he RETURNed in the acquisition mode if the target was still the highest priority and intervisible.

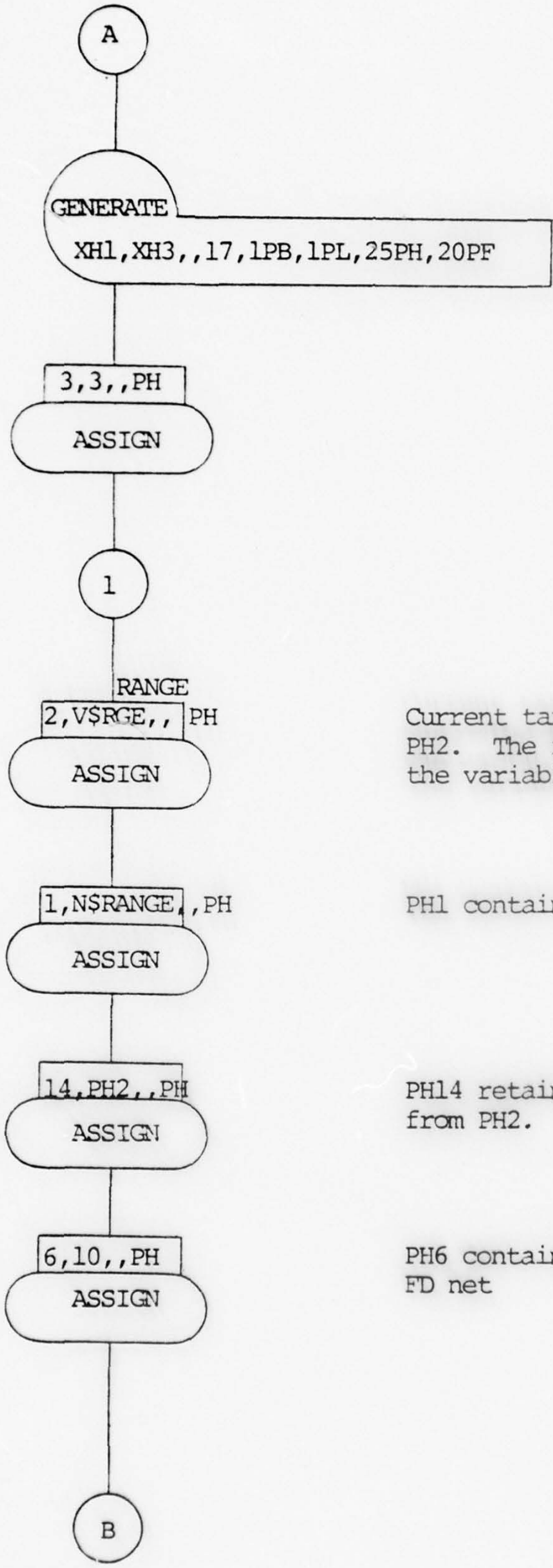
The functions and variables that were defined to drive the model are presented in Appendix C including brief explanations of each.

FIELD ARTILLERY BATTERY FIRE SUPPORT MODEL BLOCK DIAGRAM



Generates 17 targets in each FO zone. The interarrival times at each GENERATE block are U [XH1,XH3] .

The FO zone is stored in half-word parameter 3.

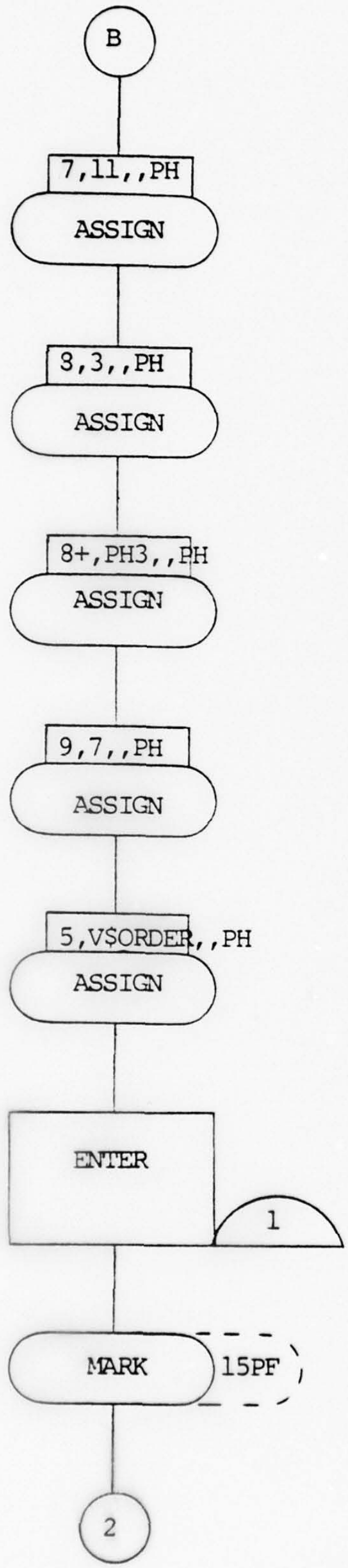


Current target range is stored in PH2. The range is the value of the variable RGE.

PH1 contains the target number.

PH14 retains the initial range from PH2.

PH6 contains the number of the FD net



PH7 contains the number of the FB.

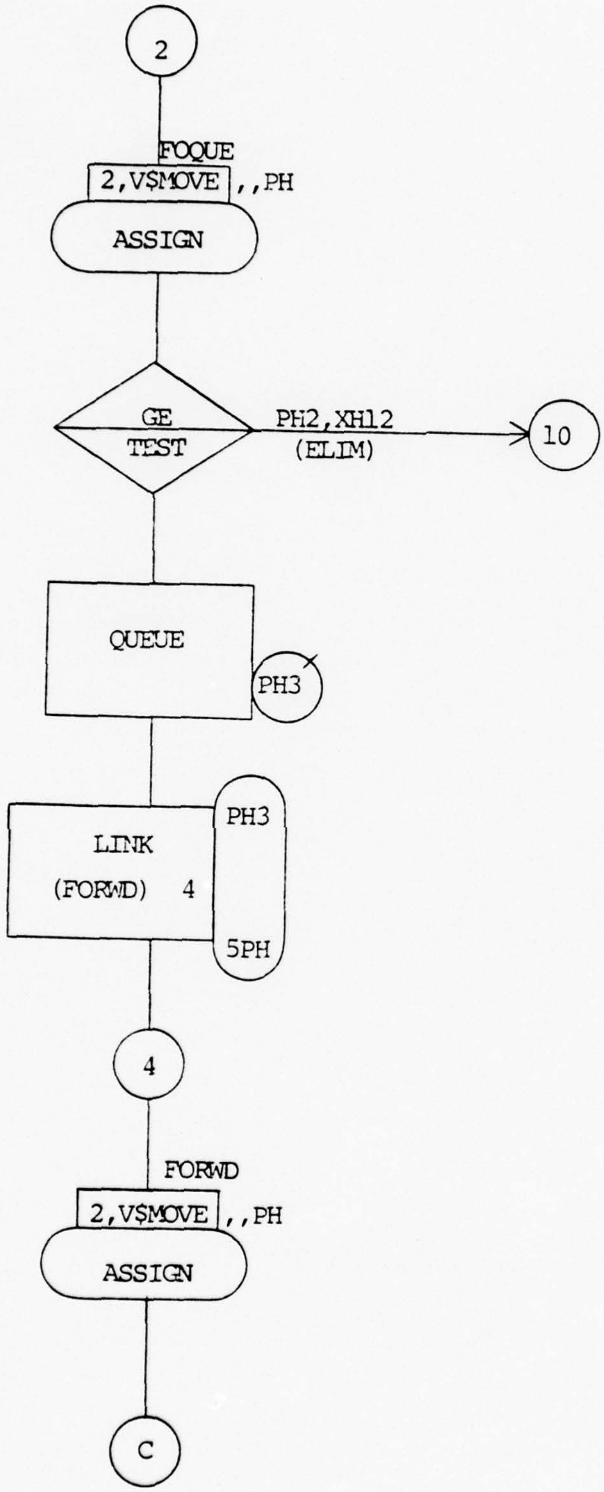
PH8 determines the number of the queue for requests completed.

PH9 defines the FDC to handle the mission.

Range relative to starting time of attack is calculated by ORDER and placed in PH5.

Target enters the combat zone.

Current clock time is plac[illegible] in PF15.

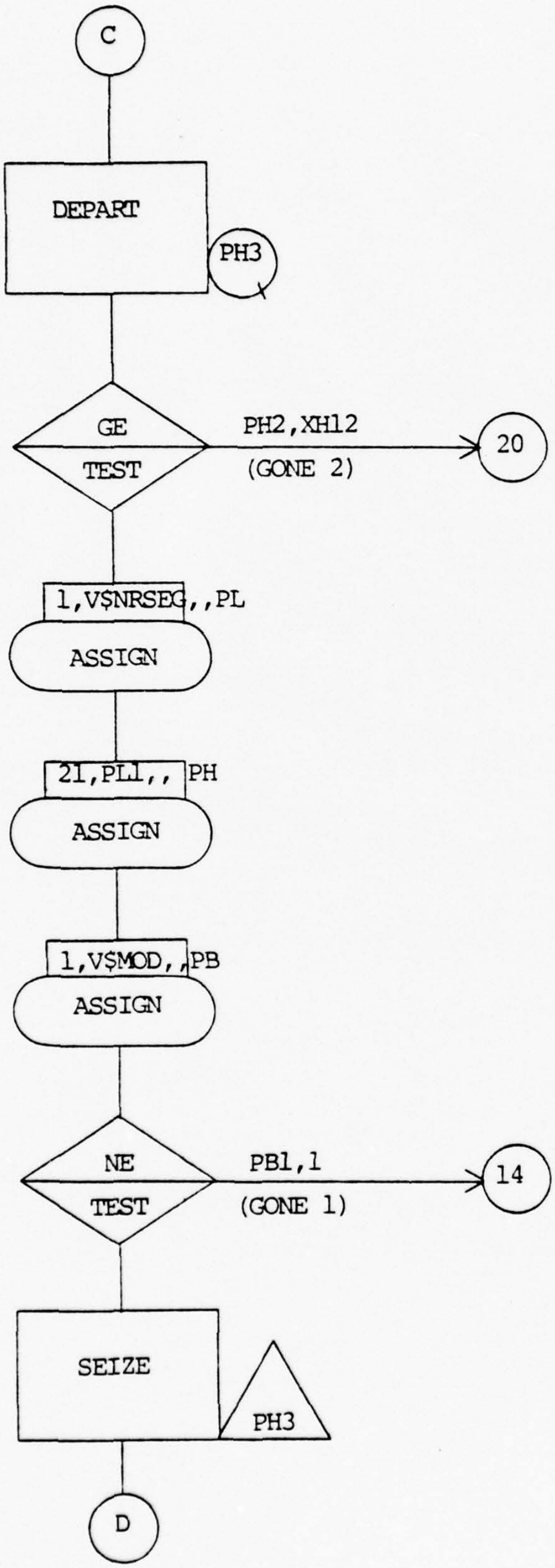


Current range is updated by MOVE.

Range is tested. If PH2 is less than XH12 the target is eliminated.

Target enters the FO queue designated by PH3.

It is linked on the user chain according to the modified range.



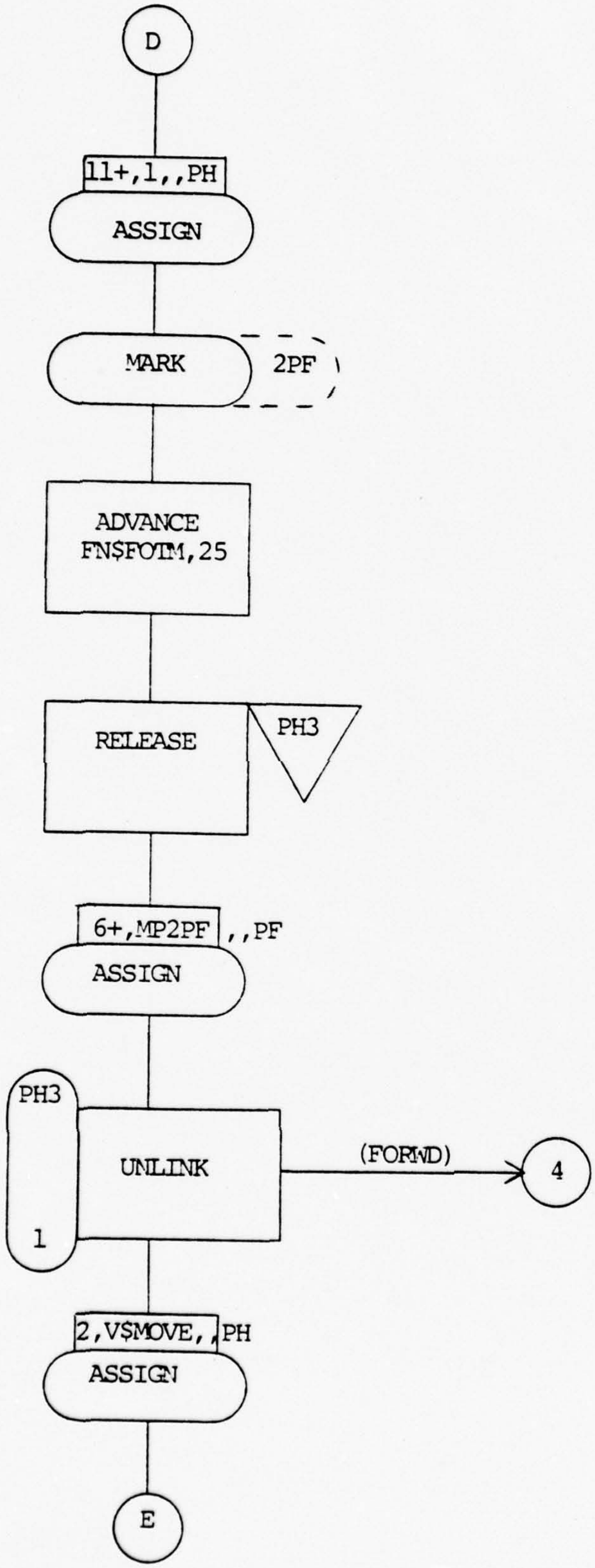
Departs FO queue.

Target is tested for range.

Three blocks are used in conjunction with the following TEST block to determine if a target is intervisible.

If target is noninter-visible it is not processed by the FO.

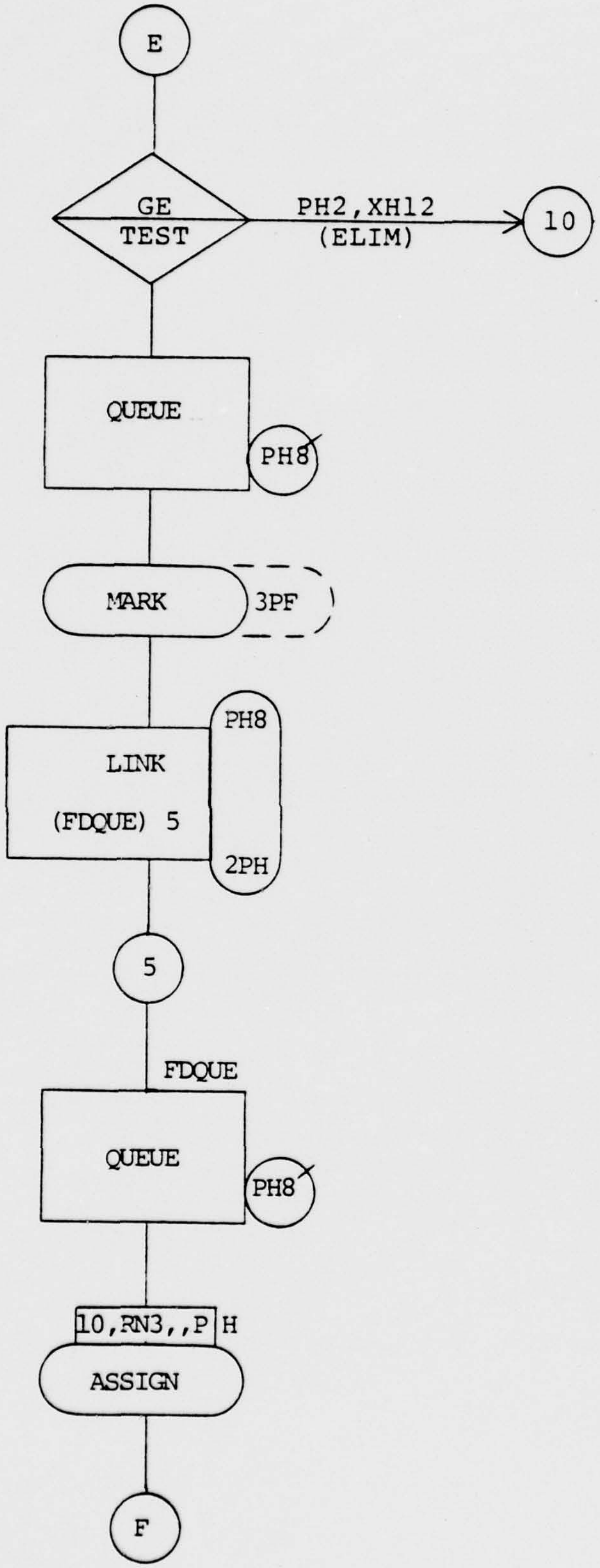
FO begins to write up request for fire.



Delay to process target. The time is distributed uniformly over the interval with range 5 seconds

Target is located and request for fire is ready to be sent.

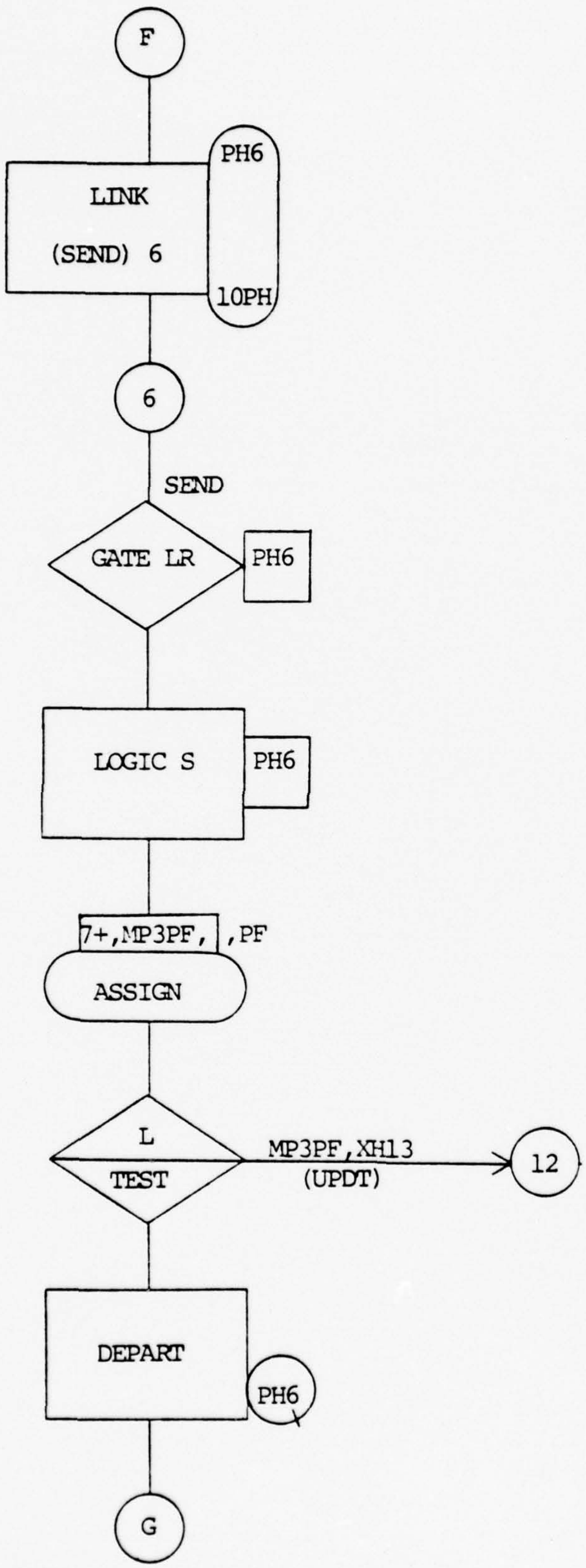
Allows another target to be placed in front of FO.



Request for fire is placed in queue of finished requests

Requests are prioritized by range in the FO queue of finished missions.

Once a target is the highest priority for the FO, it enters the FD net queue designated by PH6 for transmission to FDC.



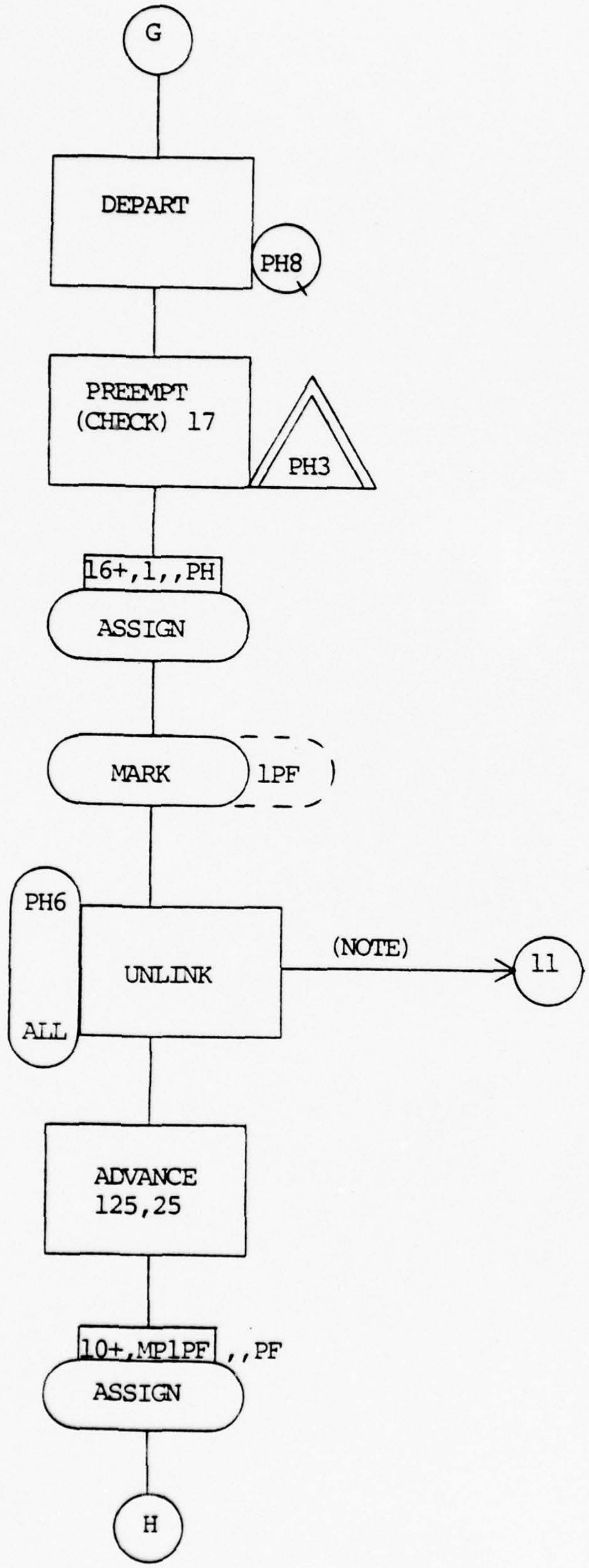
FD Net is a random selection queue based upon value PH10.

Simulates the FD Net designated by PH6.

Denies others access to FD net designated by PH6

XH13 contains the threshold time for declaring a request for fire stale. If the value XH13 is exceeded, the target is updated at UPDT.

Departs FD net queue.

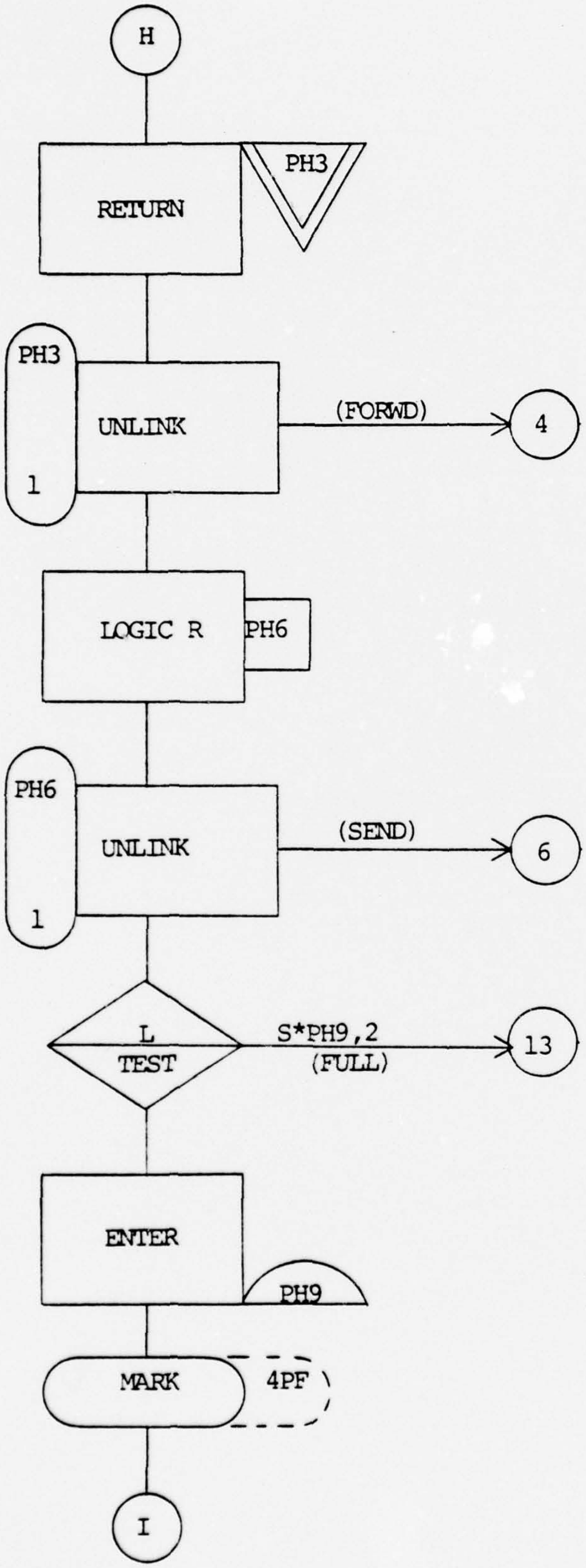


Departs FO waiting-transmission queue.

FO is preempted to send the mission. The preempted target is sent to CHECK.

Sends all remaining transactions in queue PH6 to NOTE to be reshuffled.

Transmission time on FD net is uniformly distributed [10,15] seconds.



Returns the FO to processing mode after request is received at FDC.

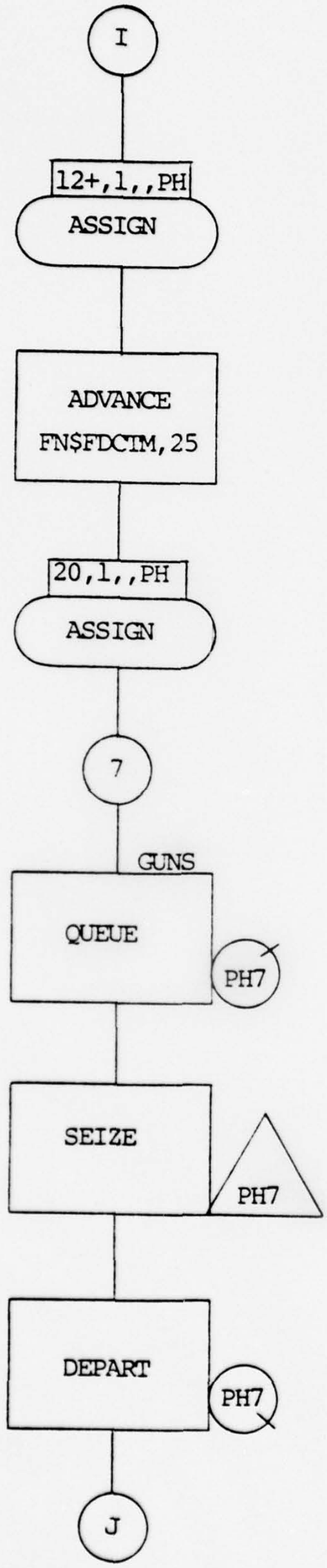
Sends next target to FO

Reopens the FD net

Sends next mission to FD net

If FDC designated by PH9 has two missions in progress the mission at the TEST block is sent to FULL.

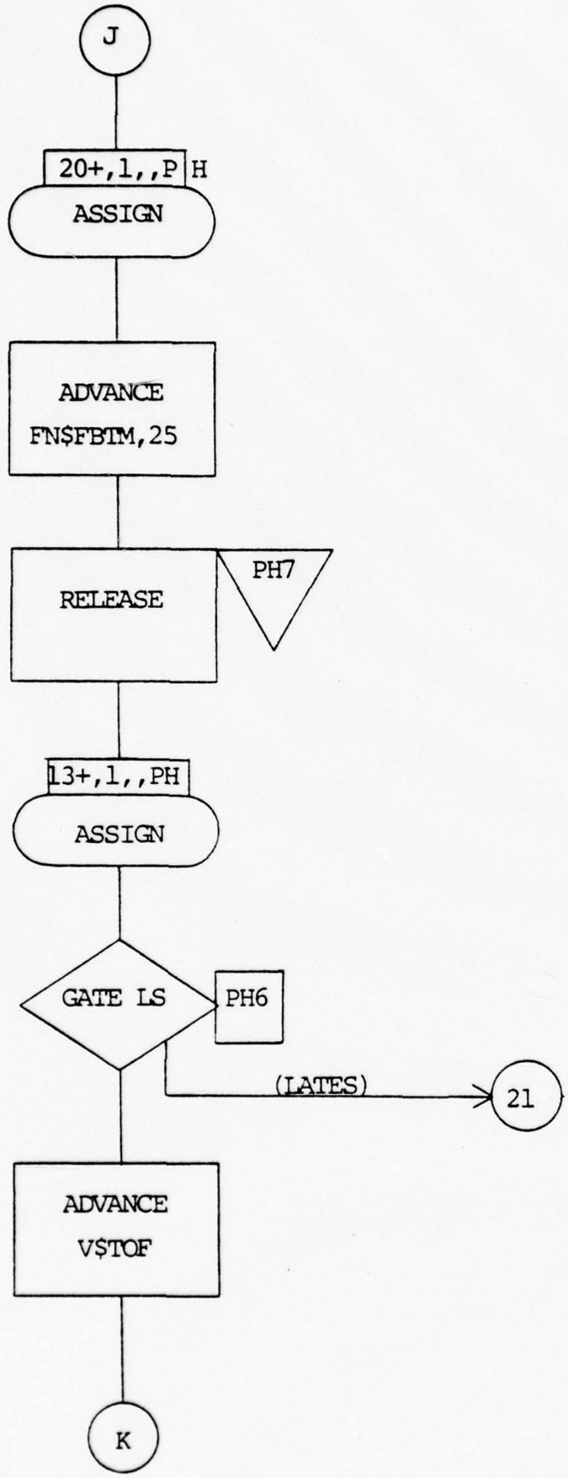
Request for fire enters FDC designated by PH9.



Calculates FDC computation time.

Target enters queue for the FB designated by PH7.

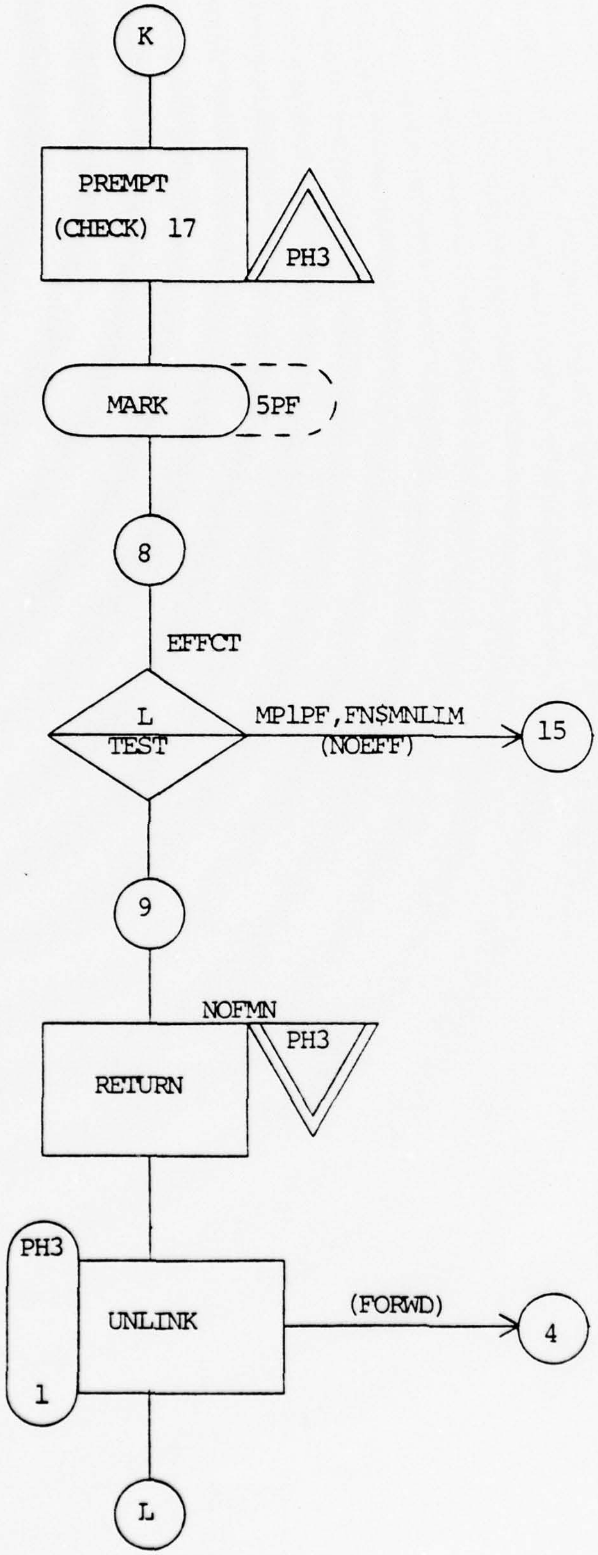
FB fires the mission.



Calculates FB service time according to function FBTM.

If the FD net is busy the FDC cannot warn the FO that the FB has just shot his mission.

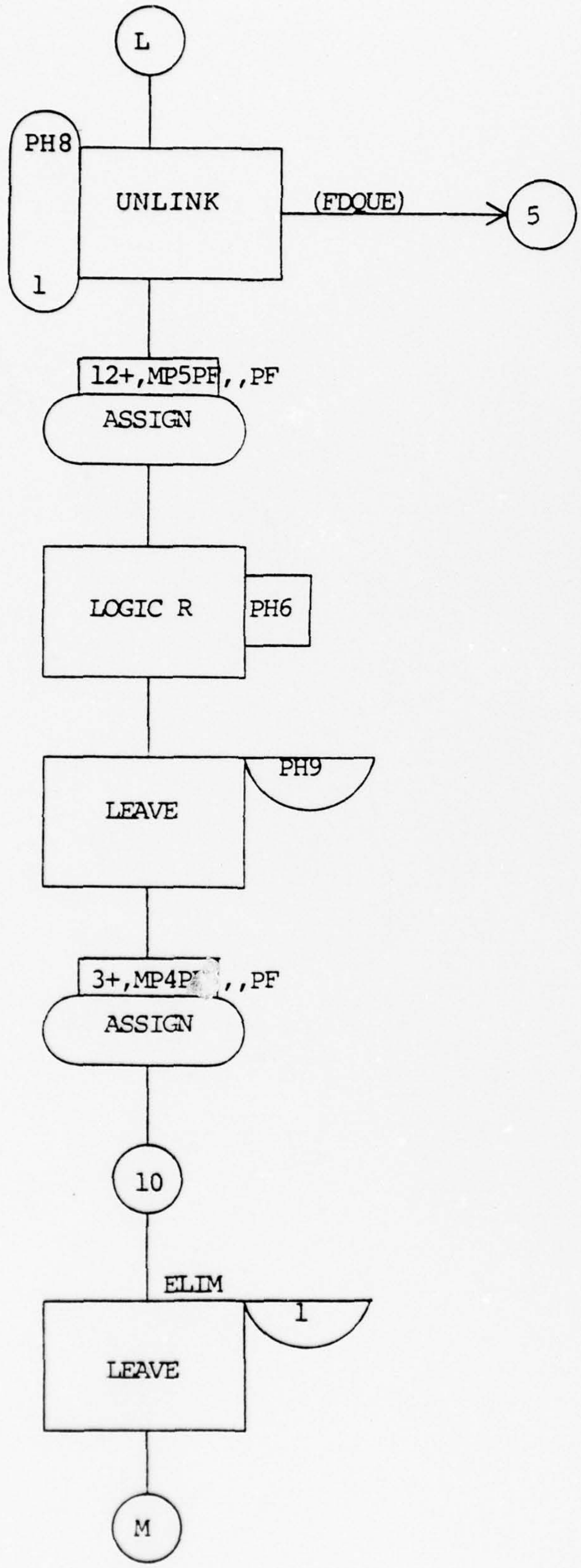
Delay for time of flight calculated by TOF.



If unwarned of the mission the FO first begins his adjustment when he sees rounds in his area.

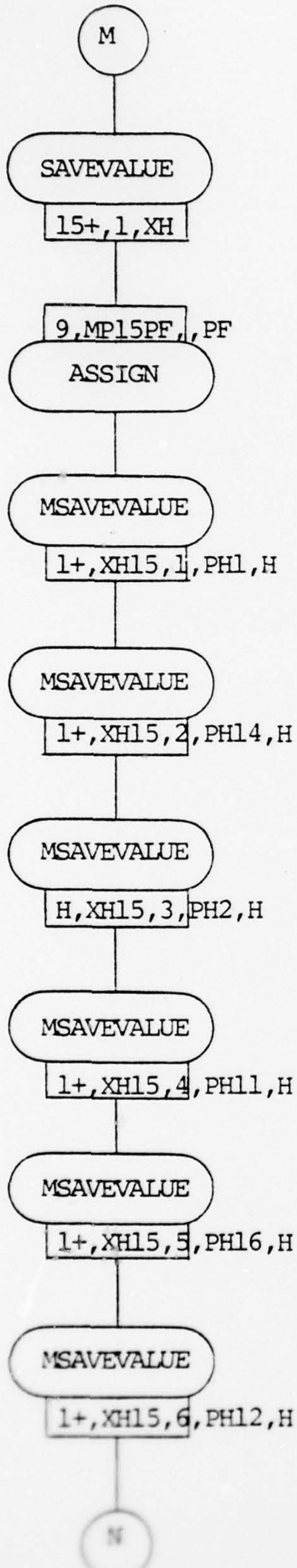
If the mission completion time is less than the value of MNLIM, it was effective. If not it had no effect and begins reprocessing at NOEFF.

Fire mission is ended. FO returns to target processing mode.



FDC has finished the mission.

Target is eliminated from the battle from the FO point of view.



Assigns full word parameter 9 the total transit time for the target.

Assigns target number to Column 1.

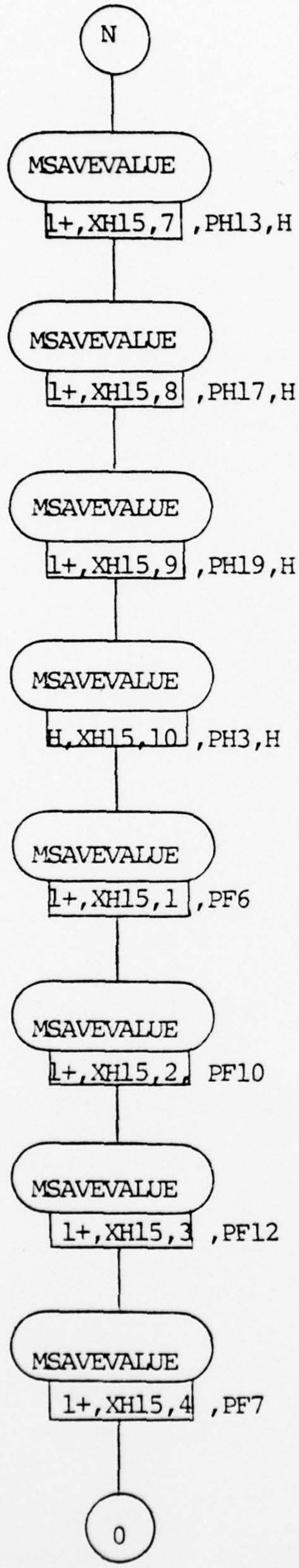
Assigns initial range to Column 2.

Assigns final departure range to Column 3.

Assigns number of times processed by FO to Column 4.

Assigns number of times transmitted to FDC to Column 5.

Assigns number of times processed by FDC to Column 6.



Assigns number of times the FB engaged the target to Column 7.

Assigns number of times the target was preempted at the FO to Column 8.

Assigns number of times the target was nonintervisible to Column 9.

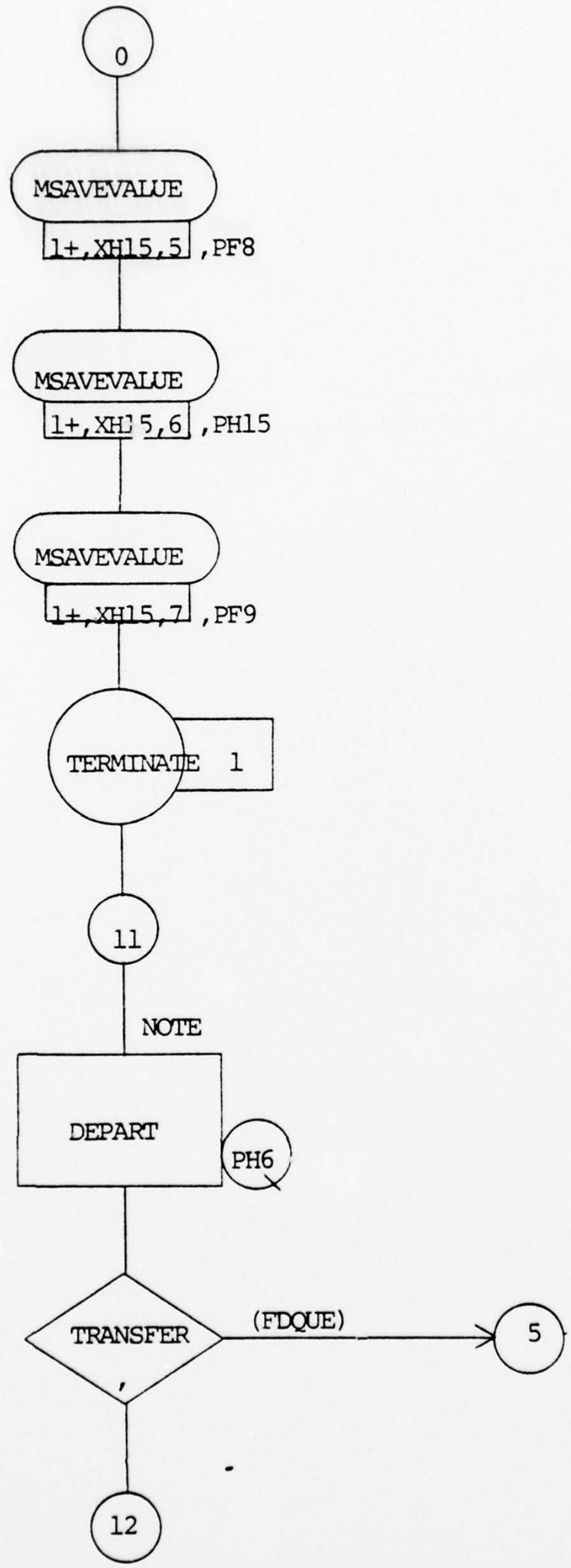
Assigns FO number to Column 10.

Assigns successful FO fire mission processing time to Column 1.

Assigns FO transmitting time to Column 2.

Assigns FO adjustment time to Column 3.

Assigns total time waiting to be transmitted to Column 4.



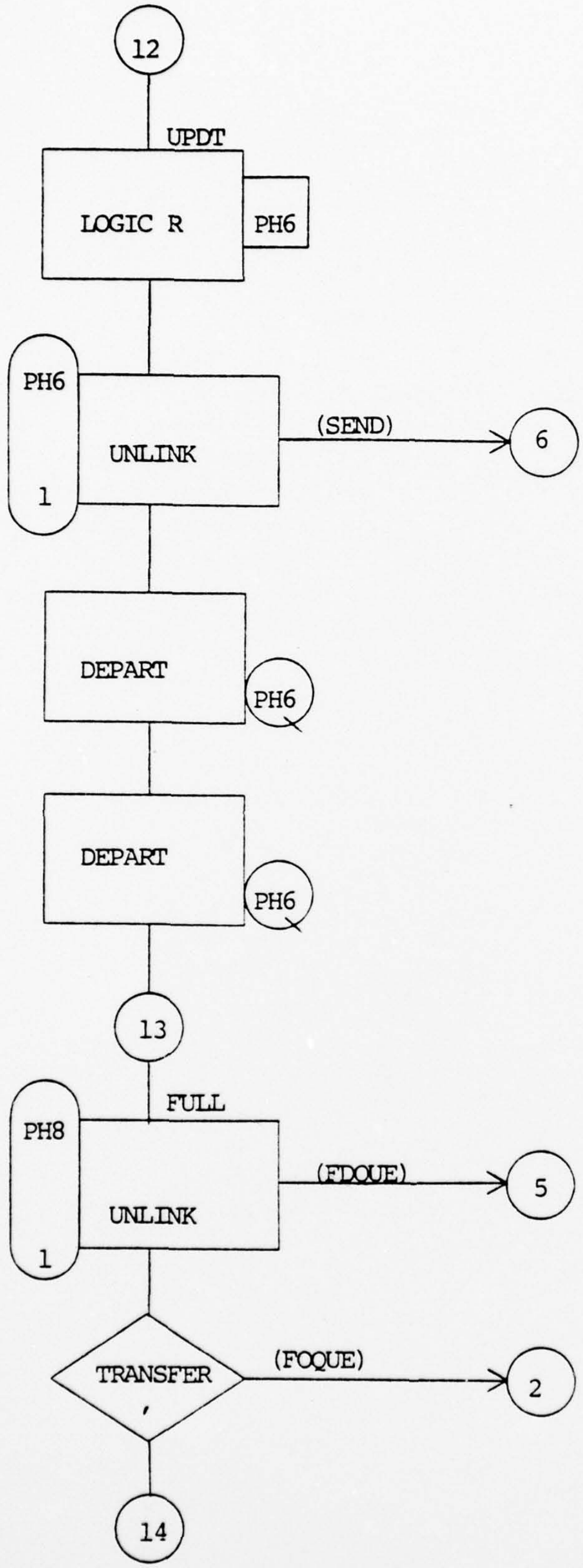
Assigns total FDC/FB time to Column 5.

Assigns time total generated nonintervisible to Column 6.

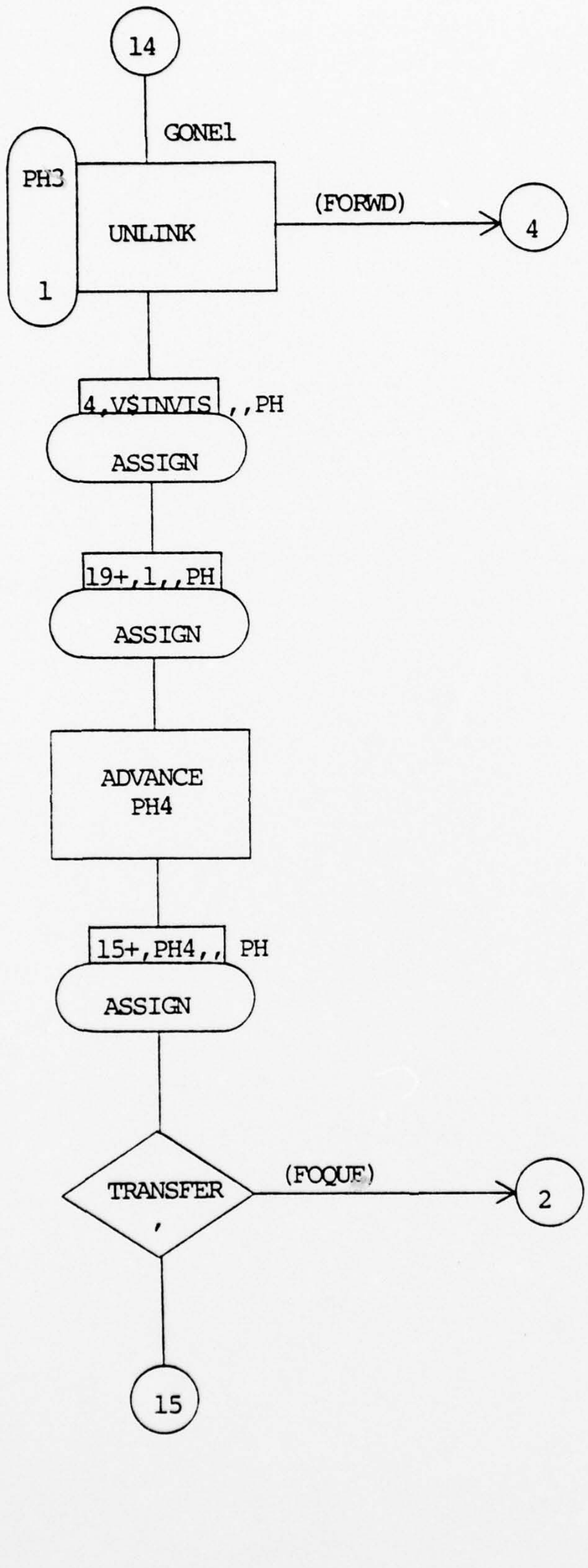
Assigns total target duration time to Column 7.

The target transaction is removed from the program.

Missions are sent through these blocks and redirected into the FD net queue with new random numbers.



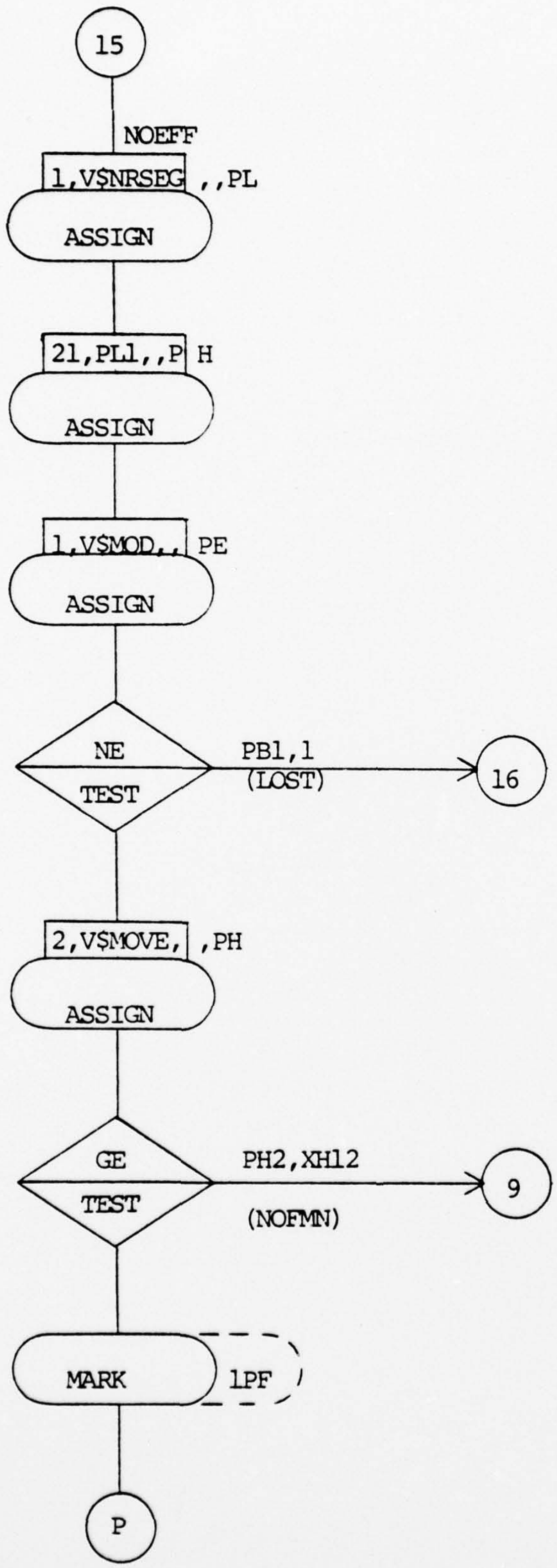
Prior to transmitting the FO will choose not to send his message if it is stale. Blocks 12 - 14 perform the operations of closing the net, and eliminating the transaction from the queues.



If the target was nonintervisible, INVIS calculates that time remaining until it is intervisible.

The nonintervisible target is delayed the value of PH4.

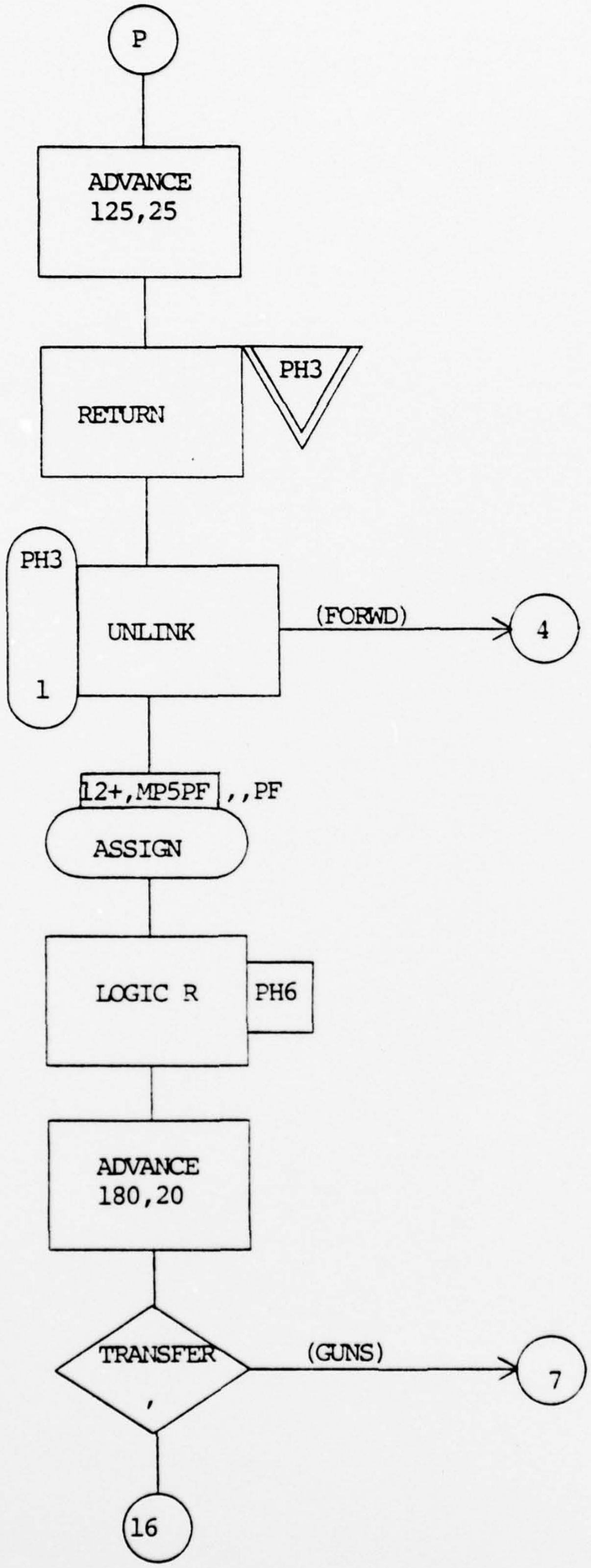
The now intervisible target is integrated back into the target stream.



If there was no effect on the first firing, blocks 15 to M determine if the target is still intervisible.

If it is not still intervisible the target is sent to LOST.

If target is still an artillery target we attempt to reengage. If not the mission is ended.

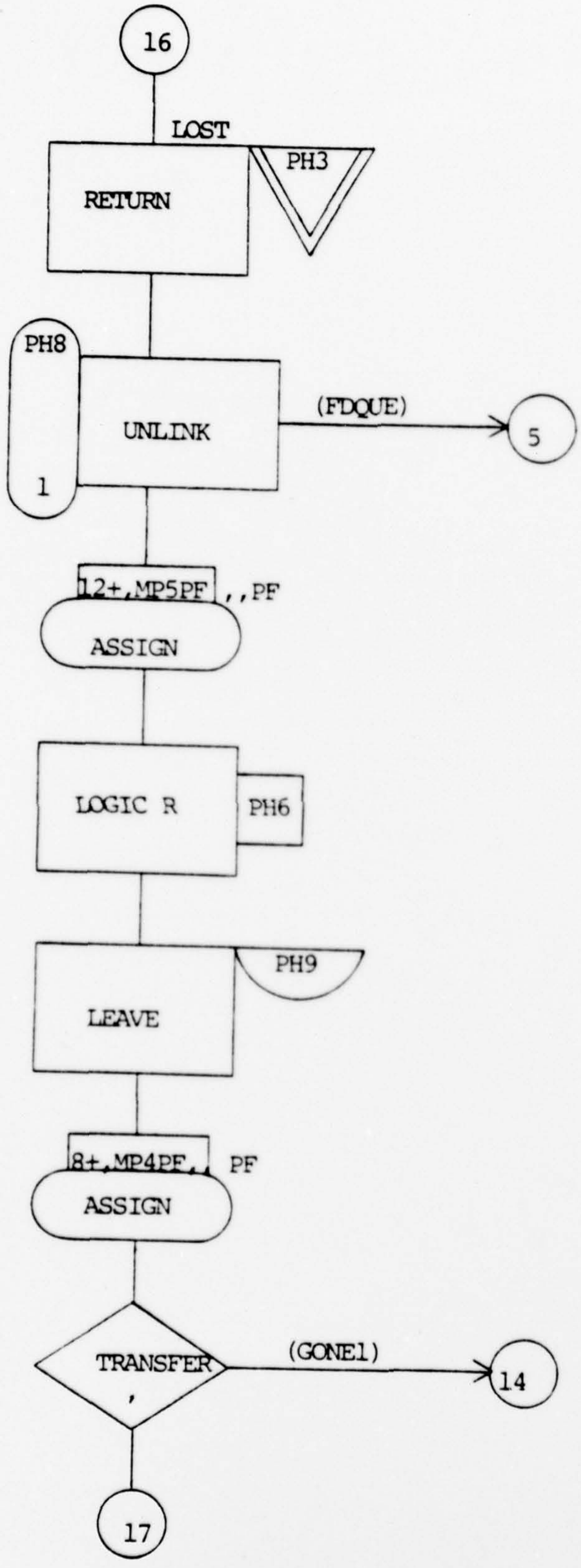


Time to make an adjustment on the rounds and transmit to FDC.

FO is returned to target processing.

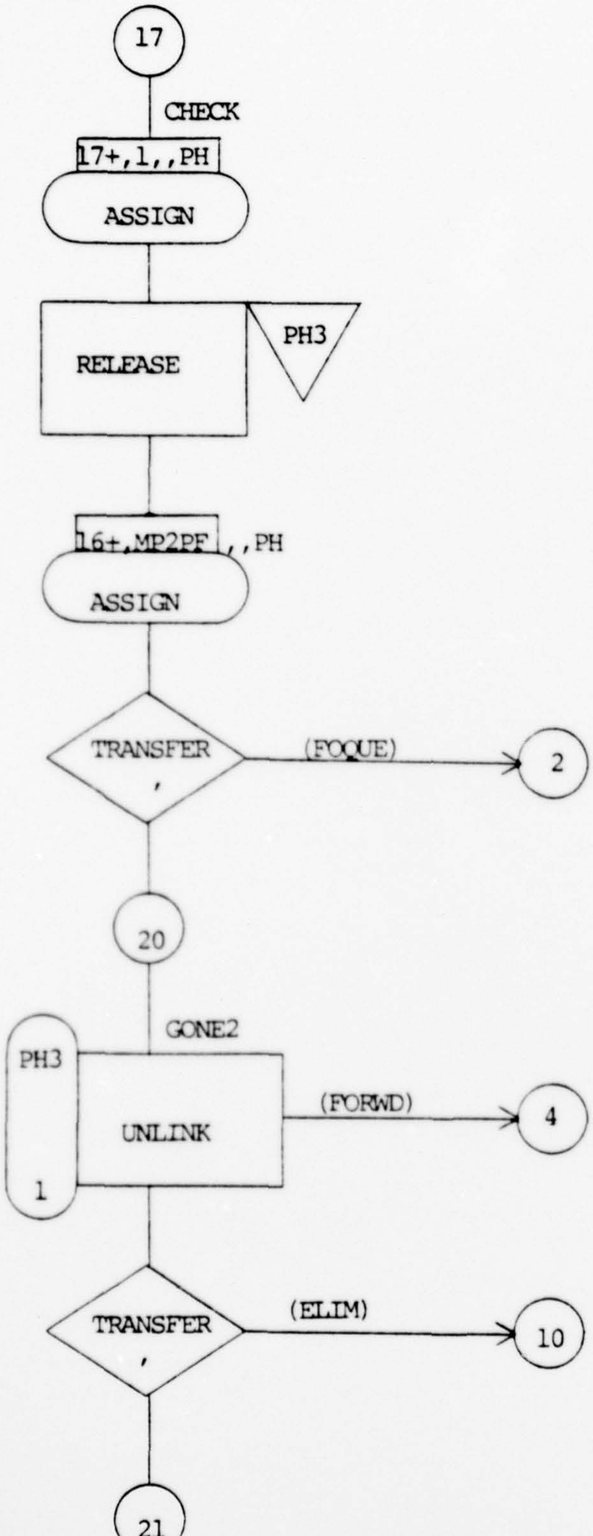
FDC calculates the necessary adjustment data.

Sends the data to the FB at GUNS.



If the target was not intervisible no adjustment of the last rounds is possible. The FO is returned to other duties.

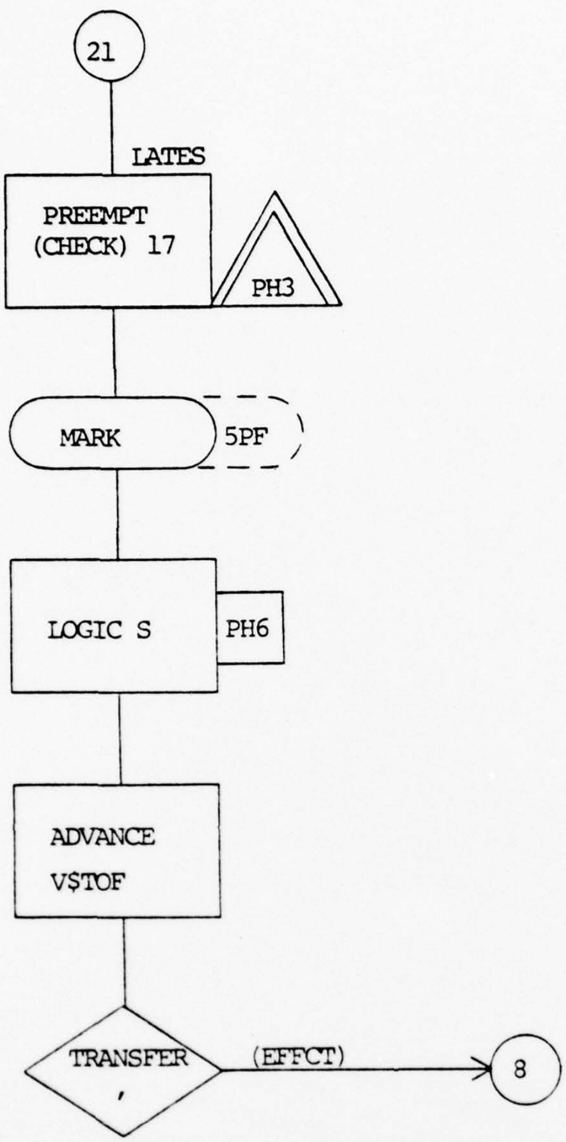
The FDC gives end of mission.



When the FO is preempted to send a message to the FDC, the mission in the initial processing phase is removed from the FO facility and returned to the queue.

Allows FO to begin processing another mission.

The reneging target is eliminated.



Given notification of the FB service the FO drops other duties and waits for the rounds to impact.

TABLE E-I FO UTILIZATION (CASE 1)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.862	.945	.943	78.8	16.1	5.1	38
2	.875	.900	.941	76.6	17.2	6.2	38
3	.994	.857	.893	79.8	14.4	5.8	33
4	.951	.839	.940	78.6	16.3	5.1	37
5	.881	.891	.995	79.2	15.8	5.0	36
6	.957	.938	.912	79.6	15.0	5.4	34
7	.897	.932	.994	78.9	16.2	4.9	34
8	.828	.870	.997	78.5	16.5	5.0	36
9	.962	.875	.995	78.0	16.6	5.4	35
10	.853	.937	.880	78.8	16.0	5.2	35
$\overline{X}$	.906	.899	.949	78.68	16.01	5.31	35.6
SD	.06	.02	.04	.90	.80	.41	1.71
95% CI	[.789; 1.000]	[.863; .935]	[.848; 1.000]	[76.6; 80.7]	[14.2; 17.8]	[4.4; 6.2]	[31.7; 39.5]

TABLE E-II FO UTILIZATION (CASE 2)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSING
1	.849	.857	.990	80.6	14.5	4.9	19
2	.876	.991	.917	80.3	13.5	6.2	17
3	.995	.871	.867	82.1	13.1	4.8	16
4	.994	.846	.905	82.7	11.9	5.4	15
5	.948	.922	.946	80.9	13.5	5.6	16
6	.981	.988	.978	81.6	14.0	4.4	17
7	.868	.941	.992	81.5	12.1	6.4	15
8	.845	.887	.877	79.6	15.2	5.2	19
9	.989	.939	.944	82.2	12.7	5.1	16
10	.984	.900	.930	82.4	12.8	4.8	16
$\overline{X}$	.933	.914	.935	81.39	13.33	5.28	16.6
SD	.06	.05	.03	1.01	1.04	.64	1.43
95% CI	[.789; 1.000]	[.790; 1.000]	[.859; 1.000]	[79.1; 83.7]	[11.0; 15.7]	[3.8; 6.7]	[13.4; 19.8]

TABLE E-III FO UTILIZATION (CASE 3)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.843	.997	.890	78.7	15.0	6.3	61
2	.959	.943	.891	78.8	15.3	5.9	68
3	.871	.997	.879	80.0	15.1	4.9	63
4	.988	.891	.807	77.9	16.5	5.6	68
5	.997	.835	.924	78.8	15.6	5.6	66
6	.797	.998	.848	79.1	14.9	6.0	63
7	.911	.949	.948	79.1	15.7	5.2	66
8	.943	.847	.997	79.8	14.3	5.9	64
9	.978	.897	.997	80.2	15.0	4.8	65
10	.941	.902	.800	77.4	16.5	6.1	69
$\overline{X}$	.923	.926	.898	78.98	15.39	5.63	65.3
SD	.06	.05	.07	.88	.70	.51	2.58
95% CI	[.780; 1.000]	[.804; 1.000]	[.737; 1.000]	[77.0; 81.0]	[13.8; 17.0]	[4.5; 6.8]	[59.5; 71.1]

TABLE E-IV FO UTILIZATION (CASE 4)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.887	.995	.804	82.4	13.4	4.2	34
2	.988	.993	.947	80.9	13.7	5.4	33
3	.925	.995	.967	83.1	12.5	4.4	31
4	.995	.986	.949	80.8	13.5	5.7	32
5	.848	.874	.997	82.7	12.2	5.1	30
6	.908	.876	.996	81.5	13.4	5.1	33
7	.995	.863	.910	81.5	13.4	5.1	32
8	.936	.963	.995	80.7	14.0	5.3	33
9	.914	.867	.997	82.1	13.8	4.1	33
10	.962	.980	.996	82.6	12.2	5.2	31
$\overline{X}$	.938	.941	.956	81.83	13.21	4.96	32.2
SD	.05	.06	.06	.87	.66	.54	1.23
95% CI	[.833; 1000]	[.794; 1000]	[.826; 1000]	[79.9; 83.8]	[11.7; 14.7]	[3.7; 6.2]	[29.4; 35.0]

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TABLE E-V FO UTILIZATION (CASE 5)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.867	.960	.938	77.7	16.9	5.4	42
2	.883	.997	.851	80.2	14.8	5.0	37
3	.908	.864	.897	77.3	18.0	4.7	39
4	.815	.963	.905	79.0	15.3	5.7	37
5	.835	.987	.882	78.6	16.6	4.8	41
6	.930	.834	.930	78.0	16.0	6.0	39
7	.973	.881	.905	79.1	16.7	4.2	40
8	.902	.857	.911	78.2	16.9	4.9	41
9	.956	.790	.923	80.5	13.5	6.0	34
10	.920	.804	.911	77.6	17.3	5.1	43
$\overline{X}$	.899	.894	.905	78.62	16.2	5.18	39.3
SD	.05	.08	.03	1.09	1.33	.59	2.71
05% CI	[.790; 1000]	[.722; 1.000]	[.832; .978]	[76.2; 81.1]	[13.2; 19.2]	[3.4; 7.0]	[33.2; 45.4]

TABLE E-VI FO UTILIZATION (CASE 6)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.847	.885	.833	80.5	14.0	5.5	21
2	.878	.978	.896	80.8	13.4	5.8	21
3	.969	.872	.867	82.4	12.6	5.0	19
4	.963	.895	.847	80.5	13.9	5.6	20
5	.937	.883	.815	83.0	11.9	5.1	20
6	.945	.984	.855	80.1	14.5	5.4	22
7	.899	.847	.917	80.0	13.4	6.6	20
8	.850	.916	.994	81.0	13.2	5.8	19
9	.970	.864	.844	82.5	12.2	5.3	20
10	.915	.895	.971	83.6	11.8	4.6	20
$\overline{X}$	.917	.902	.884	81.45	13.09	5.47	20.2
SD	.05	.05	.06	1.29	.93	.54	.92
95% CI	[.796; 1000]	[.800; 1000]	[.752; 1000]	[78.5; 84.3]	[11.0; 15.2]	[4.2; 6.7]	[18.1; 22.3]

TABLE E-VII FO UTILIZATION (CASE 7)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.813	.937	.990	79.4	14.7	5.9	66
2	.822	.989	.892	78.3	15.9	5.8	61
3	.873	.885	.997	78.5	15.6	5.9	65
4	.683	.996	.715	80.9	14.7	4.4	67
5	.995	.920	.881	79.0	15.2	5.8	70
6	.972	.880	.903	78.4	15.9	5.7	71
7	.996	.821	.836	79.1	15.5	5.4	67
8	.800	.821	.993	80.6	14.2	5.2	62
9	.808	.916	.959	78.2	15.4	6.4	67
10	.823	.803	.997	79.8	15.0	5.2	65
$\overline{X}$	.859	.897	.916	79.22	15.21	5.57	66.1
SD	.10	.06	.09	.96	.56	.55	3.11
95% CI	[.641; 1000]	[.750; 1000]	[.702; 1000]	[77.1; 81.4]	[13.9; 16.5]	[4.3; 6.8]	[59.1; 73.1]

TABLE E-VII FO UTILIZATION (CASE 8)

RUN	FO 1 UTILIZATION	FO 2 UTILIZATION	FO 3 UTILIZATION	BREAKDOWN OF FO TIME % ACQ TM	% TRANS TM	% ADJ TM	TOTAL TGTS PROCESSED
1	.896	.989	.925	80.7	13.8	5.5	36
2	.976	.981	.930	80.4	14.5	5.1	37
3	.986	.855	.939	80.3	13.7	6.0	38
4	.991	.901	.912	79.8	13.7	6.5	37
5	.849	.851	.987	82.0	13.3	4.7	36
6	.948	.986	.962	81.2	13.5	5.3	38
7	.947	.904	.980	80.1	14.0	5.9	37
8	.992	.959	.936	82.2	12.5	5.3	35
9	.929	.941	.980	80.7	13.7	5.6	38
10	.831	.996	.870	81.5	13.0	5.5	36
$\overline{X}$	.935	.936	.942	80.89	13.57	5.54	36.8
SD	.05	.06	.04	.81	.55	.50	1.03
95% CI	[.825; 1000]	[.799; 1000]	[.854; 1000]	[79.1; 82.7]	[12.3; 14.8]	[4.4; 6.7]	[34.5; 39.1]

TABLE E-IX FIRE MISSION STATISTICS (CASE 1)

RUN	FDC UTILIZATION	FDC # FM	FDC # TGTS	FB UTILIZATION	FB # VOLLEYS	AVE QUEUE
1	.78	23	23	.63	23	.05
2	.81	22	20	.64	24	.09
3	.72	20	19	.56	21	.09
4	.78	22	21	.62	23	.07
5	.75	21	20	.60	22	.08
6	.76	21	20	.60	22	.06
7	.75	21	20	.60	22	.06
8	.74	20	19	.58	22	.06
9	.75	21	20	.60	22	.07
10	.78	22	21	.62	23	.06
$\overline{X}$	.782	21.3	20.3	.605	22.4	.069
SD	.03	.95	1.16	.02	.84	.01
95% CI	[.70; .82]	[19.2; 23.4]	[17.7; 22.9]	[.55; .66]	[20.5; 24.3]	[.04; .10]

TABLE E-X FIRE MISSION STATISTICS (CASE 2)

RUN	FDC UTILIZATION	FDC # FM	FDC # TGTS	FB UTILIZATION	FB # VOLLEYS	FB AVE QUEUE
1	.71	12	11	.56	13	.08
2	.73	11	11	.57	12	.08
3	.66	10	9	.51	11	.09
4	.67	10	9	.51	11	.11
5	.65	9	8	.49	10	.09
6	.66	9	7	.50	10	.08
7	.63	8	7	.48	10	.10
8	.66	11	9	.53	12	.09
9	.68	10	10	.52	11	.08
10	.62	9	8	.48	10	.07
$\overline{X}$	.669	9.9	8.9	.515	11.0	.087
SD	.05	1.19	1.45	.03	1.05	.01
95% CI	[.56; .78]	[7.2; 12.6]	[5.6; 12.2]	[.44; .58]	[8.6; 13.4]	[.06; .11]

TABLE E-XI FIRE MISSION STATISTICS (CASE 3)

RUN	FDC UTILIZATION	FDC # FM	FDC # TGTS	FB UTILIZATION	FB # VOLLEYS	FB AVE QUEUE
1	.80	39	38	.58	41	.03
2	.80	42	41	.59	42	.01
3	.79	37	36	.58	39	.05
4	.82	40	40	.59	42	.04
5	.81	40	38	.58	41	.04
6	.79	38	37	.56	41	.07
7	.82	40	38	.59	41	.05
8	.78	38	38	.55	40	.04
9	.83	38	36	.57	40	.09
10	.80	41	40	.59	42	.04
$\overline{X}$	.804	39.3	38.2	.578	40.9	.05
SD	.02	1.57	1.69	.01	.99	.007
95% CI	[.76; .84]	[35.8; 42.8]	[34.4; 42.0]	[.55; .61]	[38.7; 43.1]	[0; .02]

TABLE E-XII FIRE MISSION STATISTICS (CASE 4)

RUN	FDC UTILIZATION	FDC # FM	FDC # TGTS	FB UTILIZATION	FB # VOLLEYS	FB AVE QUEUE
1	.71	19	18	.49	21	.06
2	.71	20	20	.51	20	.02
3	.71	19	18	.51	20	.06
4	.74	19	19	.53	20	.06
5	.70	19	17	.50	21	.05
6	.71	20	17	.51	21	.08
7	.69	19	18	.50	20	.05
8	.75	20	19	.54	21	.96
9	.71	19	19	.51	20	.06
10	.73	19	18	.55	21	.08
$\overline{X}$	.721	19.3	18.3	.515	20.5	.058
SD	.03	.48	.95	.02	.53	.02
95% CI	[.66; .78]	[18.2; 20.4]	[16.2; 20.4]	[.47; .56]	[19.3; 21.7]	[.02; .10]

TABLE E-XIII FIRE MISSION STATISTICS (CASE 5)

RUN	FDC UTILIZATION	FDC # FM	FDC # TGTS	FB UTILIZATION	FB # VOLLEYS	FB AVE QUEUE
1	.78	26	26	[illegible]	26	.02
2	.77	24	23	.59	25	.06
3	.78	23	22	.61	25	.09
4	.76	24	21	.60	25	.11
5	.77	24	23	.61	25	.06
6	.79	24	23	.62	26	.10
7	.77	23	19	.60	24	.10
8	.77	23	19	.59	25	.11
9	.74	21	20	.56	24	.08
10	.79	24	22	.60	26	.08
$\overline{X}$	.772	23.6	21.8	.601	25.1	.081
SD	.01	1.26	2.15	.02	.74	.03
95% CI	[.74 .81]	[20.7; 26.5]	[16.9; 26.7]	[.56; .64]	[23.4; 26.8]	[.02; .14]

TABLE E-XIV FIRE MISSION STATISTICS (CASE 6)

RUN	UTILIZATION	FDC # FM	# TGTS	UTILIZATION	FB # VOLLEYS	AVE QUEUE
1	.65	14	13	.51	14	.06
2	.69	13	13	.53	15	.09
3	.67	13	11	.52	13	.07
4	.67	12	9	.51	13	.10
5	.65	13	12	.51	14	.08
6	.71	14	13	.56	15	.06
7	.69	14	14	.56	15	.06
8	.61	12	11	.49	12	.05
9	.71	14	14	.55	15	.07
10	.63	12	11	.51	13	.08
$\overline{X}$	.67	13.1	12.1	.525	13.9	.072
SD	.03	.88	1.59	.02	1.1	.02
95% CI	[.60; .74]	[11.1; 15.1]	[8.5; 15.7]	[.47; .58]	[11.4; 16.4]	[.04; .11]

TABLE E-XV FIRE MISSION STATISTICS (CASE 7)

RUN	UTILIZATION	FDC # FM	# TGTS	UTILIZATION	FB # VOLLEYS	AVE QUEUE
1	.82	38	37	.58	43	.09
2	.80	42	42	.58	42	.01
3	.80	41	40	.58	42	.03
4	.67	36	36	.47	37	.02
5	.83	40	37	.58	44	.10
6	.81	42	42	.58	44	.06
7	.76	40	38	.55	41	.05
8	.73	36	36	.51	39	.06
9	.78	41	39	.57	42	.05
10	.77	40	39	.55	41	.05
$\overline{X}$	.777	39.6	38.6	.555	41.5	.052
SD	.05	2.22	2.21	.04	2.17	.03
95% CI	[.67; .89]	[34.6; 44.6]	[33.6; 43.6]	[.47; .64]	[36.6; 46.4]	[0; .12]

TABLE E-XVI FIRE MISSION STATISTICS (CASE 8)

RUN		FDC			FB	
	UTILIZATION	#FM	# TGTS	UTILIZATION	# VOLLEYS	AVE QUEUE
1	.78	23	22	.56	24	.04
2	.78	23	22	.57	24	.05
3	.76	22	20	.55	24	.08
4	.76	24	22	.56	25	.06
5	.70	22	22	.50	23	.03
6	.78	22	19	.55	24	.09
7	.77	23	21	.56	24	.07
8	.73	21	19	.51	23	.08
9	.77	23	21	.56	24	.06
10	.70	21	18	.49	23	.08
$\overline{X}$	.753	22.4	20.6	.541	23.8	.064
SD	.03	.97	1.51	.03	.63	.02
95% CI	[.68; .82]	[20.2; 24.6]	[17.2; 24.0]	[.47; .61]	[22.4; 25.2]	[.02; .11]

TABLE E-XVII BATTLE STATISTICS (CASE 1-8)

	AVG TOTAL SERVICE TIME (min)							
RUN/CASE	1	2	3	4	5	6	7	8
1	16.6	10.4	31.9	19.0	18.6	12.2	33.3	19.6
2	16.7	9.3	32.3	17.8	19.0	12.3	32.9	18.9
3	16.8	9.6	31.4	17.8	18.1	11.2	32.7	19.6
4	16.7	9.6	31.7	17.1	19.1	11.6	35.9	20.0
5	16.4	9.1	32.0	18.7	18.7	12.2	34.0	20.3
6	16.3	8.8	33.0	18.7	18.8	11.7	34.0	19.4
7	16.7	9.1	31.1	18.5	18.2	11.9	34.2	19.2
8	16.8	10.2	32.3	17.5	19.3	11.1	34.2	19.5
9	16.2	9.1	31.2	18.3	19.1	12.1	33.5	19.4
10	16.8	9.2	32.6	17.0	19.3	11.5	33.9	20.9
$\overline{X}$	16.60	9.44	31.95	18.04	18.82	11.78	33.86	19.68
SD	.22	.51	.62	.70	.42	.43	.89	.58
95% CI	[16.1; 17.1]	[8.3; 10.6]	[30.6; 33.3]	[16.5; 19.6]	[17.9; 19.8]	[10.8; 12.8]	[31.8; 35.9]	[18.4; 21.0]
AVG TM/FM (sec)	46.8	57.2	48.8	56.1	47.8	54.0	51.3	52.7
AVG TM/TGT (sec)	49.1	63.6	50.2	59.1	51.8	58.4	52.6	57.3
AVG TM/RD (sec)	44.5	51.5	46.9	52.8	45.0	50.8	49.0	49.6

TABLE E-XVIII RANGE OF ENGAGEMENT

	CASE 2,6			CASE 1,5			CASE 4,8			CASE 3,7		
A	B	C	D	B	C	D	B	C	D	B	C	D
1000	210	20.6	100.	421	41.3	100.	389	38.1	100.	768	75.3	100.0
1200	151	14.8	71.9	334	32.7	79.3	351	34.4	90.2	725	71.1	94.4
1400	126	12.4	60.0	266	26.1	63.2	320	31.4	82.3	670	65.7	87.2
1600	100	9.8	47.6	212	20.8	50.4	298	29.2	76.6	627	61.5	81.6
1800	80	7.8	38.1	173	17.0	41.1	280	27.5	72.0	582	57.1	75.8
2000	64	6.3	30.5	148	14.5	35.1	261	25.6	67.1	554	54.3	72.1
2200	46	4.5	21.9	109	10.7	25.9	246	24.1	63.2	520	51.0	67.7
2400	28	2.7	13.3	56	5.5	13.3	236	23.1	60.7	494	48.4	64.3
2600	20	2.0	9.5	33	3.2	7.8	218	21.4	56.0	460	45.1	59.9
2800	8	.8	3.8	19	1.9	4.5	197	19.3	50.6	432	42.4	56.3
3000	3	.3	1.4	7	.7	1.7	181	17.7	46.5	394	38.6	51.3
3200	1	.1	.5	4	.4	1.0	162	15.9	41.6	362	35.5	47.1
3400	0	.0	.0	0	.0	.0	145	14.2	37.3	329	32.3	42.8
3600							134	13.1	34.4	298	29.2	38.8
3800							115	11.3	29.6	264	25.9	34.4
4000							100	9.8	25.7	230	22.5	29.9
4200							87	8.5	22.4	193	18.9	25.1
4400							68	6.7	17.5	156	15.3	20.3
4600							56	5.5	14.4	119	11.7	15.5
4800							27	2.6	6.9	83	8.1	10.8
5000							20	2.0	5.1	42	4.1	5.5
5200							14	1.4	3.6	24	2.4	3.1
5400							4	.4	1.0	14	1.4	1.8
5600							3	.3	.8	6	.6	.8
5800							0	.0	.0	2	.2	.3
6000										0	.0	.0

Note: Column A contains 200 meter intervals.

Column B contains the cumulative number of targets engaged prior to the range indicated in Column A for each composite case.

Column C contains the cumulative percentage of the enemy regiment engaged prior to the range in Column A for each composite case.

Column D contains the cumulative percentage of the engaged targets that were engaged prior to the range in Column A for each case.

TABLE E-XIX AVERAGE SERVICE TIME OF I-TH TARGET

	CASE 1,5		CASE 2,6		CASE 3,7		CASE 4,8	
TGT	TIME	%	TIME	%	TIME	%	TIME	%
1	2.28	1.96	2.28	1.96	2.36	1.96	2.35	1.96
2	3.05	3.92	2.99	3.92	3.16	3.92	3.18	3.92
3	3.89	5.88	3.74	5.88	3.96	5.88	3.99	5.88
4	3.94	7.84	4.11	7.84	4.31	7.84	4.76	7.84
5	4.81	9.80	5.10	9.80	5.31	9.80	5.51	9.80
6	5.92	11.76	5.47	11.76	5.85	11.76	6.26	11.76
7	6.05	13.73	6.12	13.73	6.74	13.73	7.19	13.73
8	7.56	15.69	6.64	15.49	7.74	15.69	7.94	15.69
9	7.89	17.65	7.20	17.06	8.39	17.65	8.56	17.65
10	8.59	19.61	7.47	18.24	8.68	19.61	9.22	19.61
11	9.22	21.57	7.58	19.31	9.86	21.57	10.11	21.57
12	9.87	23.53	8.12	19.90	10.82	23.53	10.91	23.53
13	10.27	25.49	8.13	20.39	11.22	25.49	11.78	25.49
14	10.72	27.45	8.74	20.59	12.21	27.45	12.34	27.45
15	11.36	29.41			12.98	29.41	13.00	29.41
16	12.06	31.37			13.84	31.37	13.71	31.37
17	12.75	33.33			14.40	33.33	14.26	33.33
18	13.47	35.29			15.28	35.29	14.67	35.10
19	14.08	37.25			16.10	37.25	14.75	36.37
20	14.76	39.31			16.93	39.22	15.33	37.16
21	14.81	41.27			17.26	41.18	15.45	37.75
22					17.95	43.14	16.10	38.14
23					19.14	45.10		
24					20.21	47.06		
25					20.89	49.02		
26					21.44	50.98		
27					22.17	52.94		
28					22.95	54.90		
29					23.46	56.82		
30					24.30	58.82		
31					25.23	60.78		
32					25.78	62.75		
33					26.21	64.71		
34					26.74	66.67		
35					27.37	68.63		
36					28.50	70.59		
37					29.04	72.16		
38					29.00	73.43		
39					29.47	74.22		
40					29.58	74.80		
41					29.72	75.10		
42					30.21	75.29		

Note: Unit of time is minutes.

Percentage columns represent that portion of the enemy regiment engaged by the time given in the TIME columns.

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